REPORT 411
(Amended Edition)

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ADVISORY GROUP FOR AERONAUTICAL RESEARCH AND DEVELOPMENT

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MEDICAL INDOCTRINATION FOR FLYERS

AN AEROMEDICAL HANDBOOK FOR AIRCREWS

1963

NORTH ATLANTIC TREATY ORGANIZATION

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MEDICAL INDOCTRINATION FOR FLYERS

AN AEROMEDICAL HANDBOOK FOR AIRCREWS

Sponsored by the Editorial Committee of the
Aero-Space Medical Panel of AGARD

SUMMARY

This Aeromedical Handbook is designed to provide aircrews with a more complete understanding of the biological sciences affecting present-day flying. It is not an exhaustive treatment of all the aeromedical factors and aircrews should discuss any questions arising with their own Flight Surgeons.

The material is taken almost verbatim from Royal Canadian Air Force Pamphlet 69, 'Fit to Fly', with minor deletions and additions.

SOMMAIRE

Ce manuel aéromédical est dans le but de fournir aux équipages d'avions un moyen de compréhension plus complet des sciences biologiques qui intéressent les conditions de vol d'aujourd'hui. Il ne s'agit pas d'une étude complète de tous les facteurs aéromédicaux et les équipages d'avions devraient discuter toute question survenant au fur et à mesure avec leurs propres chirurgiens d'escadrille.

La matière a été empruntée presque verbatim à la brochure No.69 'Fit to Fly' (Apte à voler) des forces aériennes canadiennes, à quelques additions et suppressions près.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

		Page
Fig. 19	The 'leans'	62
Fig. 20	The ear in cross-section	71
Fig. 21	The eye in horizontal cross-section	87
Fig. 22	Field of vision	88
Fig. 23	Off-centre vision	90
Fig. 24	Scanning at night	91

CHAPTER 1

PHYSIOLOGY

OR

'THE OPERATIONAL CHARACTERISTICS OF YOUR BODY'

A. General

(1) Physiology is the study of the manner in which the cells, tissues and organs of your body perform their normal functions. This study is important, not only in helping us to understand ourselves, but also in making us realize that man has been endowed with unique resources which increasingly complex machines allow us to exploit. Man's ability to make decisions based on his experience, his tremendous tolerance to changes in his environment, and his flexibility, must be fully utilized if the utmost potentialities of flight are to be realized. In other words, both your physiological capabilities and your limitations must be understood if you are to perform efficiently under the conditions that today's high-speed, high-altitude flight demand of you.

(2) The human body is made up of millions of microscopic cells which require a surrounding fluid-environment of nearly constant composition and temperature to function properly. In man, each of the various parts and organs of the body is highly specialized for the particular function which it is called upon to perform. Because all the body's energy eventually comes from intracellular oxidation of food products, your cells must be supplied continuously with oxygen and with a means of ridding themselves of the toxic end-products of this reaction. This is achieved by means of the circulatory or cardiovascular system in which many cells work together as a highly integrated and efficient unit.

B. Circulatory System

(1) If the central nervous system can be compared to a complicated telephone exchange, then the circulatory system must be considered not only the railway but also the ventilation, cooling, drainage, courier, and anti-invasion system. (See Figure 1.)

(2) The blood circulates through the body in a completely closed system consisting of a pump – the heart – and a network of tubes – the blood vessels. The heart is a rather remarkable organ as it is capable of changing its output from four quarts *(3.8 litres)* a minute at rest to about six quarts *(5.8 litres)* a minute during walking and as high as twenty-nine quarts *(27.8 litres)* a minute during strenuous exercise. These marvellous performance characteristics are due to the unique design feature of the heart which provides for a short rest between each beat. During the period of rest, the oxygen supply to the heart muscle is replenished and the waste products are removed. This pump cycle repeats itself approximately twenty million times over a five-year period.

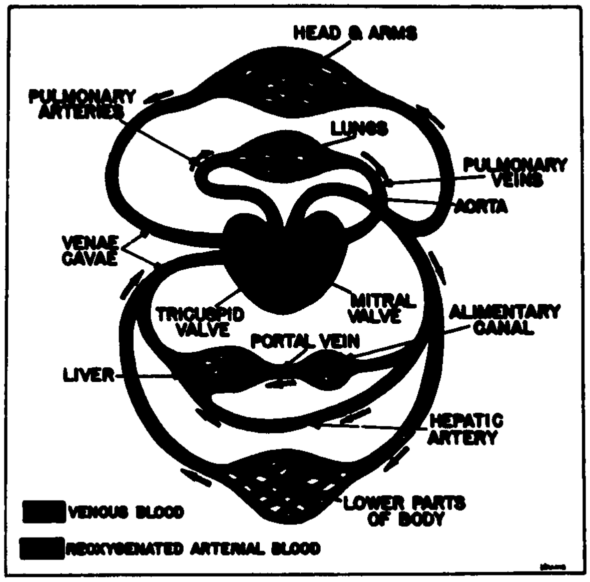


Fig. 1   Schematic diagram of the circulatory system

(3) The remainder of the circulatory system is made up of the arteries, the veins, and tiny thin-walled vessels called capillaries. The capillaries, though constituting such an inconspicuous part of the circulation, are exceedingly important. The heart is the pump and the relatively thick-walled arteries and veins simply connecting tubes which carry blood to and from the capillaries; in the capillary region the object of the circulation, viz., to convey oxygen and nutritive materials to the tissues and to carry carbon and waste products away, is fulfilled. The circulatory system contains approximately six quarts *(5.8 litres)* of blood, equivalent to about one-eleventh of the body weight. The blood has many important functions. Among these are its ability to absorb digested food from the digestive tract for transport to the body cells and to collect the waste products from the utilization of the food products. It also helps to maintain body temperature and serves to transport defence mechanisms to the site of any invasion by disease, bacteria, etc.

(4) The red corpuscles of the blood contain a protein substance called haemoglobin – the oxygen-carrying portion of the blood. (See Figure 2.) Oxygen combines loosely with this substance in the lung capillaries to form bright red arterial blood which is then carried to all parts of the body. Oxygen is removed from the blood in the tissue capillaries according to their need, leaving dark red oxygen-poor venous blood. Simultaneously the venous blood collects the end-products of cellular combustion, i.e., carbon dioxide and other waste materials. The carbon dioxide is carried to the lungs where it escapes and is breathed out; other waste materials are transported to the kidneys or the large bowel for elimination. Even this brief description should emphasize and impress upon you the vital role of the circulatory system.

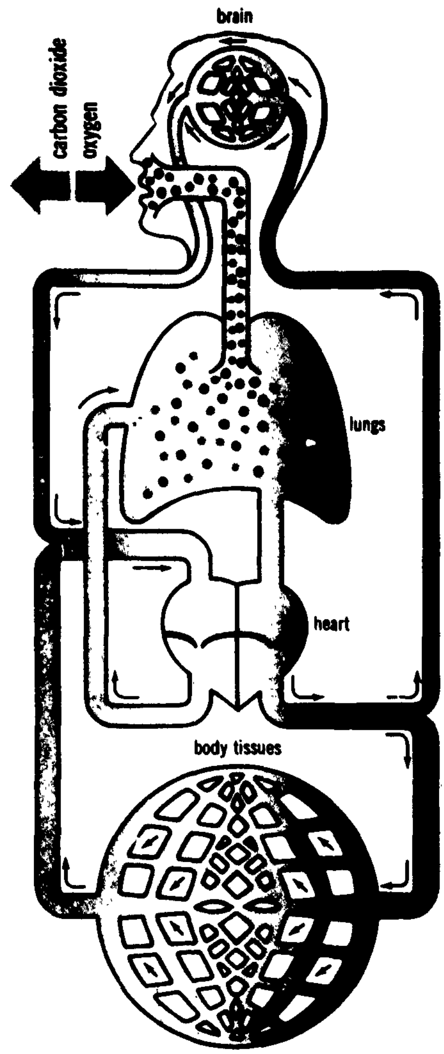


Fig. 2 Oxygen/carbon-dioxide relationship

C. **Respiratory System**

(1) All living things, with few exceptions, utilize oxygen. The oxygen combines with the carbon and hydrogen furnished by food material, producing carbon dioxide and water. These oxidation processes take place in the cells of the tissues.

(2) In one-celled animals gaseous exchange between the organism and its environment takes place directly, but in man a system of conducting tubes has been developed to bring the oxygen-containing air into his lungs. This respiratory system is designed to enable your body to utilize oxygen from the atmosphere and at the same time to excrete carbon dioxide produced by intracellular combustion.

(3) Normal inspiration is accomplished by a forward and outward movement of the ribs and a descent of the diaphragm. These movements expand the chest cavity and produce a small negative pressure inside the chest. This draws air into the lungs through the conducting tubes from the nose and mouth. The conducting tubes serve to clean, warm and saturate the air with water vapour before it reaches the terminal air sacs or alveoli. (See Figure 3.)

(4) The alveoli are very thin-walled microscopic sacs estimated to be about 750 million in number. In traversing the lung capillaries the red blood cells are separated from the alveolar air by the thin, highly-permeable membranes forming the alveolar and capillary walls. In their passage through the capillaries the red cells are, for the most part, in single file; thus a thin film of blood, having an area estimated at about 1000 square feet *(92.9 square metres)* is exposed to the alveolar air. The alveolar air (which at the end of inspiration has a relatively high concentration of oxygen and a low concentration of carbon dioxide) comes rapidly into gaseous equilibrium, oxygen diffusing from alveolar air to blood and carbon dioxide from blood to alveolar air. The blood leaving the lungs therefore contains more oxygen and less carbon dioxide than when it arrives.

(5) The alveolar air which is now rich in carbon dioxide and low in oxygen is forced out of the lungs during exhalation, accomplished by relaxation of the diaphragm and depression of the rib cage.

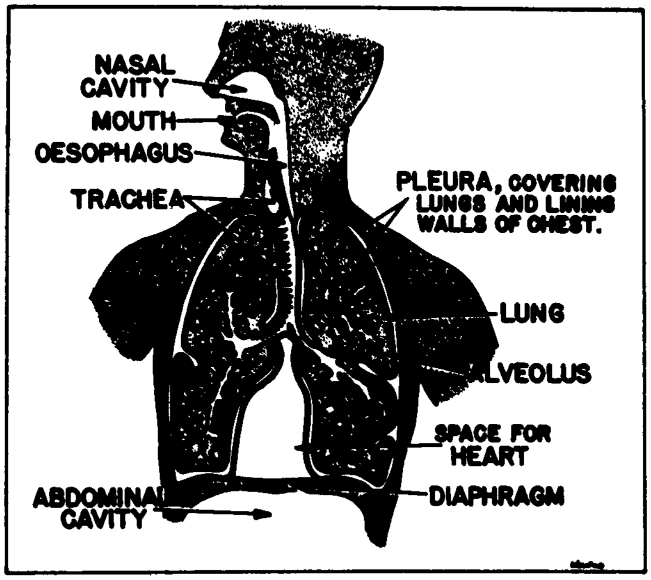


Fig.3 The respiratory system

D. Digestive System

(1) Man, like other warm-blooded animals, requires fuel in the form of food to maintain his body temperature, to furnish energy for uninterrupted functioning of his body systems, and for growth and repair of body tissues.

(2) When food is taken into the mouth and chewed, chemical substances called enzymes in the saliva begin the breakdown of the food into simpler, smaller compounds which can be utilized by the body. As this food-mixture passes from the stomach to the intestines, the chemical breakdown is carried to completion by the action of other enzymes in the digestive tract. The absorbable products of food digestion then pass through the thin walls of the small intestine into the blood stream and are transported to the liver and other tissues where they are burnt, stored, or otherwise recombined to meet body requirements. For energy purposes, the end-product of digestion is glucose, which is constantly being circulated in the blood. The remainder of the food digested that is not absorbed in the small intestine collects with other waste products in the large bowel where it is partially dehydrated, compacted, and eventually eliminated as faeces.

E. Muscular System

(1) The muscles are responsible for all the movements and much of the work done by your body. These muscles are of two types: a fast-acting type directly controlled by your will; and a relatively slow-acting type not directly controllable by your will. The most obvious function of the first type is to move the limbs, head, trunk, and other parts. The slower-acting type is more commonly concerned with the maintenance of tissue 'tone', and includes muscles which determine the cross-sectional size of blood

vessels, and muscles which mix and propel the food along the intestines during digestion. The muscles of the heart have characteristics of both types as they are capable of responding in a very rapid manner but are not directly under our voluntary control.

(2) Whether the muscles are under our voluntary control or are acting automatically, they have only one primary ability, and that is to shorten. The energy required by muscles to perform this function is supplied by the oxidation of glucose from the blood.

(3) All muscles are under the constant direction and control of the nervous system. Unless a muscle receives an impulse through its control mechanism it will not react normally. Therefore, damage to the nervous system produces paralysis of those muscle groups previously controlled by the damaged nerves. The smooth integration of the various muscle groups required to perform delicate co-ordinated tasks is accomplished through your intricate nervous system.

F. Nervous System

(1) The nervous system is the communication and control system of the body and consists of two parts: the central portion, consisting of the brain and spinal cord; and a peripheral portion consisting of nerve fibres which go to the various limbs and organs. Sensations are received by millions of specialized receptors in the skin, muscles, eyes, ears, internal organs, etc., and transmitted as electrical impulses along the nerves to the spinal cord and brain. In the brain these stimulations are co-ordinated into an overall picture of touch, pain, sound, sight, etc., which is examined by the special thought areas in the brain. There, a decision is made and the experience is either 'filed away' as a memory or some action is initiated. Impulses are transmitted by other nerve fibres to the appropriate organs or muscles which produce some body movement or internal change in response to the original stimulation. Some responses of the nervous system are automatic and never reach the conscious level, such as heart action and digestive processes. Most responses requiring body movement or speech reach the voluntary or conscious level. In other words, you are aware of the sensation while analyzing it, making a decision, and acting upon it.

(2) The nervous system is very sensitive to injury, and cells in the brain and spinal cord, once killed, never regenerate. Nerve cells are also very sensitive to damage resulting from oxygen lack, e.g., circulation failures, fatigue or starvation.

CHAPTER 2

FLYING FITNESS

A. General

(1) Man does not live in a void. He lives in his surroundings and must always be assessed in relation to his surroundings if his existence is to have any meaning or purpose. The human race has reached its present high level of development on earth largely because of its success in controlling the environment, but it has also had to adapt itself so that it fits into this environment. Aviation is a man-environment relationship in which man's fitness to engage in it has always been a matter of concern. This is increasingly so as the flight environment becomes larger and more complex. Before progressing to the specific oddities of flight that affect man, this chapter deals with the general attributes of aircrew fitness.

(2) Fitness means being fit *for* something and unless the object of the fitness is defined or implied the word has little meaning. It is obvious that a marathon runner, a wrestler, an acrobat, a fat man in the circus, a bridegroom, a scientist, and an astronaut in a space vehicle all have some form of mental or physical fitness which makes them suitable for their activity, but they are not all the same. Their fitness can only be assessed in terms of their job or purpose.

(3) Your task is to fly complex, high-powered aircraft in a strange environment and for this a special, flying fitness is required which differs in nature or degree from most other kinds of occupational fitness. Prior to service you have been examined to ensure that you have the basic physical, mental and emotional development which may be brought up to full flying fitness within the Service. The demand for higher performance in aircraft has created new stresses which have been only partly balanced by stress-protecting devices and knowledge. Therefore the demand for fitness is as great as, if not greater than, in the earlier days of flying.

(4) Flying fitness can fail in several ways:

(a) By not being developed and sustained. You need a regular application of real or artifical stresses to promote the natural tendency of the mind and body to become conditioned to its task and improve its efficiency.

(b) By a loss of the basic structural or functional attributes of health or fitness such as may be incurred by injury, sickness or age. Some of these may be wholly or partly reversible or may be compensated for by other attributes of fitness.

(c) By exhaustion of fitness potential by direct or indirect stress. This is fatigue.

B. Properties of Fitness

There are many ways of categorizing the various properties and aspects of fitness. For convenience, physical, physiological and mental aspects are discussed separately but they are by no means distinct from each other. They overlap and are complementary to form a whole picture of body fitness.

(a) *Physical Aspects.* This is related primarily to the ability of the body to meet and withstand the external forces, including gravity and acceleration, which form a constant part of the natural environment on the surface of the earth and the special environment above the earth For this, size, stature, posture, leanness, proportioning of trunk and limbs, and full joint movement are prerequisites to the proper and advantageous fitting of the man into the cockpit and its controls. These are largely determined by the time you are selected as aircrews. Of greater importance is the fitness of the muscles which gives them the properties of strength, stamina, responsiveness, flexibility, co-ordination and preparedness (tone) which are necessary for the variety of forces and fine movements involved in flying. These qualities are changeable and must be developed and maintained during a flying career. Many aircrews on entry to the Service do not have good muscular condition. It must be developed during training and, once attained, must be retained by continued effort.

(b) *Physiological Aspects.* This concerns the internal functions, or housekeeping, of the body which were described in Chapter 1. In order for the mind and limbs to meet successfully the demands of the outside environment the inner environment must be kept constantly healthy. The circulatory, respiratory, digestive, and glandular systems must be able to obtain and circulate oxygen, to supply energy, food, and essential tissue-building or chemical materials to the working body parts, to eliminate wastes such as carbon dioxide, digestive refuse and toxic materials, to control temperature, and to combat disease influences and repair tissues when injured. The vital functions of blood flow and breathing must continue without slow-down caused by external conditions.

(c) *Mental or Nervous Aspects.* This deserves separate and special mention because of its importance in co-ordinating and directing all the internal and external body functions into a smooth, efficient working unit. The brain and nervous extensions receive outside messages, understand, think, decide, and direct body parts to action, and remember everything that happens or may happen. The brain is like a computer, but unlike a computer it has greater versatility, capacity and durability. It also has feelings or emotions which may harm its operation. Of special concern to the flyer are the accurate perceptions from vision, hearing, touch, smell and balance, since without the information from these special organs of sense he is a dumb victim of his hostile surroundings. Mental ability is also dependent on motivations, attitudes, attentions, distractions, tensions, comfort, and feelings of well-being. Unless nervous fitness is present, physical and physiological fitness will be misdirected or ineffective.

C. Criteria of Fitness

(1) Physical fitness is often considered to be the key to flying fitness. The term physical fitness is usually taken to mean both physical and physiological properties as described above. Although the capability to perform physical tasks is a good, rough indicator of overall fitness, assuming the presence of the necessary structural ingredients, it is not an absolute rule. The aviator must have a high degree of mental fitness but he need not be an athlete. A man may be in excellent physical condition and still be structurally, physiologically, intellectually, or emotionally unfit for all forms of flight. The whole man must be assessed in relation to the task.

(2) There are many tests of fitness beginning with medical examinations, intelligence and aptitude tests, flight simulators, etc., and including various forms of speed and endurance tests. In the end, however, the best measure of real fitness for flight is *flight performance*, since ground assessment can only detect gross deficiencies and defects.

(3) In a very broad sense the criteria of flying fitness are as follows:

(a) the chemical processes of the body should proceed in a rapid, orderly and economical manner;

(b) the structure, quality, and power of the organs and muscles should be adequate for the body's needs and tasks;

(c) there should be accurate and delicate response by the organs of special sense; and

(d) there must be a skilful working of the central nervous system.

D. Factors Contributing to Fitness

The attainment and maintenance of fitness is largely dependent on three factors: exercise, rest, and nutrition.

(a) *Exercise*. Healthy, firm muscles and a responsive circulatory system can only be achieved by exercise. Great physical strength is not as important as endurance, stability, and rapid reaction. Exercise also helps to relieve the tensions created by working in a hazardous, emotionally-charged flying atmosphere. In the face of danger, instinct says get away but training says stay and control the danger. These antagonistic drives produce mental tension and depression which can be worked off by recreational activities on the ground. Probably the best activity is some combination of calisthenics, games, individual sports, walking, running, or swimming, performed regularly and in the open air if possible. Avoid strenuous, injurious, combative, or contact sports. Games that you like are better than games that you dislike. But exercise should not be overdone, or continued to the point of exhaustion, or exceed the limits of physique, skill, or level of training. If striving for endurance, build up slowly in easy stages. At times when the body is restricted or immobilized, such as in a small

cockpit for long periods, static exercise helps to relieve muscular tension and discomfort and assist the blood in returning to the heart rather than pooling in the extremities during inactivity. Static exercise means simply working opposing muscles against each other without actually moving bones or joints.

(b) *Rest and Sleep.* Not only are the body and mind required to respond to and perform a task but they must also recover from the effects of the effort in order to be prepared for the next task. The natural processes of the body eliminate the wastes of work, repair the worn or damaged tissues, and restore the food and oxygen storage and distribution to a state of readiness. Much of this is achieved by simple rest but mental recovery requires frequent total shut-down or sleep. Sleep requirements vary considerably among individuals, about six hours a day being a minimum and eight hours being about average. It is also important for man to assume the horizontal position during sleep or rest so that the circulatory system is relieved of the stress of pumping and controlling blood flow against the pull of gravity in the upright attitude. The muscles that hold you erect also need a rest.

(c) *Nutrition.* Food is essential for continued fitness. The amount is dependent on the work energy output. Regardless of total amounts, all healthy diets must contain a palatable, balanced mixture of protein, carbohydrate, fat, minerals, and vitamins. These are adequately provided in meat, eggs, milk, cheese, fresh and green vegetables, whole-grain cereals, enriched bread, fresh fruit, and fruit juices. With this balance even light workers on small diets do not require mineral or vitamin supplements from tonics or vitamin tablets. Aircrews who have relatively low energy requirements in their sit-down jobs must take care not to overeat since excess food is stored in the body as fat. This is unnecessary weight, is unsightly, makes you more susceptible to bends (see Chapter 10), and tends to produce certain diseases in later life. You seldom see a fat old man - the fat ones die young. Remember also that dehydration decreases efficiency, so drink plenty of water and other fluids such as milk, soup, and fruit juices. Aircrews tend to become constipated because of inactivity or inconvenience of toilet facilities. Regular habits and sufficient vegetable foods help to promote normal bowel elimination. Aircrews should always eat breakfast, for it follows a long interval without food. They should try to fit regular, normally spaced meals into flying programmes so that abnormal hunger can be avoided, particularly at the end of long flights. Take in-flight meals and between-meal supplements on long trips. A pre-flight meal should be light and tasty without heavy starches or sugars. Bulky gas-forming foods such as cabbage, turnips, bran, beans, onions, radishes or melons, if known to produce discomfort while flying, should be avoided.

E. Factors Detrimental to Fitness

It is obvious that any deficiency of exercise, rest or nutrition can have an adverse effect on fitness. However, there are many influences that decrease fitness in a more positive manner. A few of the more prominent ones will be mentioned.

(a) *Alcohol.* In spite of the pleasure and relaxation that it may give, alcohol is still a body poison and will seriously interfere with fitness so that it should never be taken in any quantity when demands on flying fitness are anticipated. Alcohol acts on the body by retarding the oxidation in the individual cells so that it has its greatest effect on cells having a very vigorous oxygen utilization normally, such as the brain cells. It is a depressant, not a stimulant. It may appear to be stimulating because it first destroys the brain functions controlling inhibitions, especially those related to conduct and social behaviour. At the same time perception, judgment, speed of reaction and co-ordination are also depressed. It may prompt you to spit on the floor but does not improve your aim if you do. The effects are very lasting since alcohol is slowly eliminated from the body. It takes about one hour for the body to get rid of the amount of alcohol in one beer or cocktail. If you drink at a faster rate than this the body alcohol content rises steadily and it takes much longer to remove it. Do not drink at all in the eight-hour period before flying and do not over-indulge less than twenty-four hours before flying. Since drinking episodes may lead to very late nights the combination of lack of sleep and alcohol after-effects may be seriously damaging to mental and physical ability the following morning even though eight hours may have elapsed.

(b) *Tobacco Smoking.* Like drinking, smoking is a pleasurable poison. In excess, tobacco smoke with its carbon monoxide, nicotine, and cancer-producing ingredients, has both immediate and delayed harmful effects on fitness. Carbon monoxide resulting from the incomplete combustion of tobacco exists in all tobacco smoke in amounts ranging from one to eight per cent. It has an affinity for haemoglobin, the oxygen-carrying material in the red cells of the blood. Absorbed from the lungs of smoke inhalers it combines with haemoglobin with the exclusion of oxygen so that a mild degree of oxygen deficiency occurs. This aggravates any oxygen lack that may exist due to altitude. Nicotine is readily absorbed from lungs, nose, or mouth and adversely affects blood circulation in the extremities. It is now proved that certain substances in tobacco smoke if used for many years predispose to cancer of the lung. All considered, the pleasures of smoking are not worth the bad effects that go with it. In spite of what tobacco advertisers may say, cigarette filters remove only a small part of the harmful ingredients.

(c) *Infection.* Even mild infections like colds can hinder the normal working of the body and mind. Among other things they interfere with the ventilation of the ears and sinuses, sap the strength and initiative, and distract the mind from its task. Infection and aeroplanes do not belong together.

(d) *Drugs.* It is common practice with many people to take medicines while working. This should seldom if ever be done by aircrews and certainly not unless prescribed by the medical officer. In addition to their intended effect many drugs have undesirable side-effects such as sleepiness, nausea, weakness or elation and these cannot be predicted

accurately. If you need medication you are likely not fit to fly and it is less likely that the medicine will improve your fitness.

(e) *Stresses of Flying*. These are the unusual demands and forces of the aviation environment for which a special fitness is so necessary and which are different from those of the ground environment for which we are basically designed. But in combating these stresses fitness itself is expended so that there may not be sufficient reserve to handle adequately the primary flying tasks. The fitness-robbing stresses are such things as: oxygen lack, acceleration, noise, vibration, glare, cold, bends, disorientation, physical discomfort and exertion, injury, concentration, boredom, etc. Many of these will be considered in more detail in later chapters.

F. Fatigue

Fatigue is a difficult thing to define, describe or explain. We all know it exists and have experienced it in many ways and degrees. Perhaps the simplest way to think of it is as a temporary loss of ability to cope with a task, i.e., a loss of fitness. The factors producing it may not be associated with the task. Fatigue can be caused by the presence or absence of any of the factors already mentioned as being detrimental or contributing to fitness. The active, physical fatigue which is due to activity without recent rest and which is felt as a pleasant tiredness or lethargy or as a mild aching of muscles, is well known and common to many physical tasks. Aircrews are subject in addition to a form of mental or skill fatigue which can occur even in idleness. It is related to the concentration, responsibility, and apprehension of flying or waiting to fly. It has been said that pilots are either bored to death, worked to death, or scared to death! All of these are mentally and physically exhausting and may accumulate day by day to a chronic state known as 'pilot fatigue' unless relieved by frequent rest, recreation, or leave from duty.

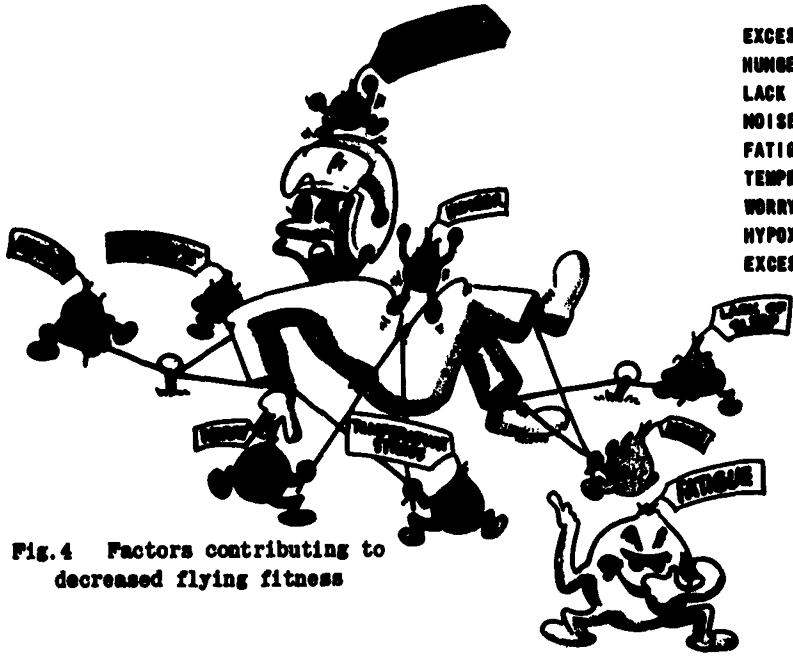


Fig.4 Factors contributing to decreased flying fitness

G. Protective Devices

Every effort is made to provide aircrews with efficient, easily operated equipment, flying aids, pleasant surroundings and recreations, but there are always stresses which cannot be predicted or avoided. The flyer as well as learning to take full advantage of his aids must be fit to handle these left-over stresses and still have enough reserve for emergency or extraordinary tests of his fitness.

H. Medical Assistance

Your Medical Officer's job is to keep you flying safely and efficiently, not to ground you. He is a doctor who has a special interest in, and has made a special study of, aviation medicine. If you feel 'under the weather', doubt your fitness to fly, or have any medical problems, consult him. Seek his advice if you are overweight. During your periodic medical examinations do not try to withhold information that may be of value in helping him to correct any real or imagined problem that you may have. If you are not completely fit you should not be assuming the responsibility of flying duties. If you fly when unfit you may jeopardize your mission, your career, your life, or the lives of others.

CHAPTER 3

CHARACTERISTICS OF THE ATMOSPHERE

A. Layers

The atmosphere is defined as the gaseous envelope which surrounds the earth. The extent of the atmosphere is estimated by the height of meteorites and the aurora borealis which depend on the presence of gas. It can be divided into five layers, viz., the troposphere, stratosphere, ozonosphere, ionosphere and exosphere. As far as we are concerned, in terms of present human flight, the atmosphere is divided into two layers: the troposphere and stratosphere. We shall discuss each separate layer below.

(a) *Troposphere*. The spherical shell of the atmosphere closest to the earth's surface, extending up to about 35,000 feet, or 7 miles *(10,658 metres)*. It is characterized by:

(i) varying moisture content,

(ii) turbulent air, and

(iii) a constant decrease in temperature with an increase in height above the earth's surface (this will be discussed further on in the chapter).

All phenomena of weather occur in this layer for these are inherently associated with the physical effects of variable temperatures, wind and moisture. In this layer icing conditions are encountered. Turbulence is also a characteristic of the troposphere.

(b) *Stratosphere*. The spherical shell of the atmosphere above 35,000 feet *(10,658 metres)*, extending to approximately 25 miles *(40 kilometres)*. It is characterized by relatively uniform temperatures due to the absence of water vapour and absence of radiation from the earth's surface. This lack of water vapour eliminates weather, therefore we are not bothered by snow, sleet, rain or icing conditions. There are no thermal currents to make flight in the stratosphere rough. However, there are constant winds that blow in horizontal planes. The area of transition between the troposphere and stratosphere is known as the tropopause. At the equator its height is greater than at the poles.

(c) *Ozonosphere*. In the upper parts of the stratosphere there exists a high-temperature region characterized by a relatively high concentration of ozone which is formed by the action on oxygen (O_2) of both ultra-violet radiation and electrical discharges as occur in the aurora borealis (northern lights). This layer, called the ozonosphere, starts at a height of 90,000 to 150,000 feet, or 17 to 30 miles *(27,432 - 45,720 metres)* above the earth's surface. Ozone is important because it absorbs a portion of the sun's radiation which would be destructive

to the eyes. The absorption of the sun's radiation by ozone is the factor which causes the rise in atmospheric temperature in this layer. High concentration of ozone will corrode metals, will affect the operation of electrical equipment, and is toxic to humans.

(d) *Ionosphere.* Evidence indicates that between 296,000 and 327,000 feet, or 56 and 62 miles *(90,220 and 99,670 metres)* above the earth's surface a rapid transition takes place from molecular oxygen (0_2) to atomic oxygen (0) which is in ionized form. At 396,000 feet or 75 miles *(120,700 metres)* above the earth's surface all the oxygen is in ionized form. In addition there is a certain amount of ionized nitrogen. The ionosphere extends to a height of approximately 400 miles *(644 kilometres)* above the earth's surface.

(e) *Exosphere.* Above 400 miles *(644 kilometres)*, on the outermost fringe of the atmosphere, gaseous molecules which are few in number travel in long elliptical orbits, bouncing outwards from impact with each other, then falling back under the effect of gravity. This region is almost indistinguishable from space.

B. Physical Characteristics

The atmosphere may be defined in terms of physical characteristics which, related to human flight, are of importance as they may affect our physiological processes. The human body is designed to function at ground level where a definite pressure is exerted on it. If this pressure is decreased, changes will occur in the body's physiological processes. It is therefore necessary for the airman who undergoes high-altitude flight to understand those physical characteristics of the atmosphere which could affect him. These are atmospheric composition, pressure, density, temperature and radiation.

C. Composition

(1) Atmospheric air is a mixture of gases which is believed to have a constant composition up to about 62 miles *(100 kilometres)*. Somewhere above this level, diffusive separation of the atmospheric gases occurs.

(2) The composition of air below 62 miles *(100 kilometres)* is:

Oxygen (0_2)...................... 21 per cent

Nitrogen (N_2).................... 78 per cent

Carbon dioxide (CO_2) and rare inert gases, e.g., neon, argon, and krypton .... 1 per cent

(3) The percentage of 0_2 is constant (21 per cent) at all reasonable altitudes. Therefore it is not a decrease in 0_2 percentage which causes hypoxia (0_2 deficiency) as the airman ascends to altitude, but a decrease in its partial pressure.

D. Atmospheric Pressure

(1) Air pressure decreases from its sea level value as one climbs upward to the exosphere. There it is almost zero. The pressure may be measured in:

(a) pounds per square inch (psi); or

(b) pounds per square foot; or

(c) height of column of liquid it will sustain, usually mercury (Hg).

(2) Standards at mean sea level (msl) are as follows:

(a) 14.75 psi;

(b) 2116 pounds per square foot; and

(c) 760 mm Hg or 29.92 in Hg.

(3) *Law of Partial Pressures.* The air is a mixture of gases and acts in accordance with Dalton's Law of Partial Pressures which reads in part: 'a mixture of several gases, which do not react chemically, exerts a pressure equal to the sum of the pressures which the gases would exert, separately, if each were allowed to occupy the entire space alone at the given temperature'. That is, in a mixture of gases, the pressure exerted by any one gas (i.e., the individual gas pressure which is called partial pressure) is proportional to the percentage of that gas in the mixture. Therefore, the partial pressure of oxygen at sea level is $\frac{21}{100} \times 760$ or 160 mm Hg. The physiological significance of this law is that it explains the way in which ascent to altitude will induce hypoxia (O_2 deficiency). Although the percentage of O_2 in the air remains constant at all reasonable altitudes, its partial pressure will decrease in direct proportion to the total pressure.

(4) *Change of Pressure with Altitude.* With ascent into the atmosphere the total pressure of the air diminishes and therefore there is a corresponding reduction in the pressure of oxygen (O_2) in the air. Since air is compressible the density decreases with altitude so that the pressure change is not proportional to the altitude change. The high-altitude performance of an aircraft is expressed in terms of the *density* of the atmosphere. On the other hand, the physiological responses of the human body to altitude are dependent on the *pressure* of the surrounding atmosphere (pressure altitude).

(5) Figure 5 indicates that at 20,000 feet *(6,096 metres)* the barometric pressure is 349.1 mm Hg. It should be emphasized that the table states the pressure at 20,000 feet *(6,096 metres)* is 349.1 mm Hg. This is actually the average of many determinations. The barometric pressure at 20,000 feet *(6,096 metres)* above sea level may be above or below 349.1 mm Hg depending upon local conditions, high and low-pressure areas, etc.

(6) The aircraft altimeter is calibrated to agree with tables of standard atmospheric pressure for pressure and temperature lapse rates as an aircraft ascends to altitude and gives the pressure altitude when, and only when, the altimeter is set at 29.92 inches of Hg. *(76 centimetres of Hg.)*

E. Change of Temperature with Altitude

(1) Accurate description of the temperature changes in the atmosphere is rather difficult. In general, in the troposphere, there is a fairly constant decrease in temperature with altitude. This is referred to as the 'lapse rate' and is approximately 3.5°F *(2°C)* per 1000 feet *(304.8 metres)* up to 35,000 feet *(10,658 metres)*, where the temperature is -67°F. *(-55°C)*.

(2) In the stratosphere, the temperature is roughly constant at -67°F. *(-55°C.)*. At such a low temperature, the water content is so small that there is a balance between absorption of radiated heat from the earth and re-radiation to outer space. The temperature increases in the ozonosphere to a maximum of 170°F. *(76.7°C.)*. At the 210,000-foot level or 40 miles *(64,008 metres)* this high-temperature region is due to the absorption of ultra-violet radiation from the sun, and it is interesting to note that, without this layer, life on the surface of the earth, as we know it, would be impossible because of the damage to living tissue which results from heavy doses of ultra-violet radiation.

(3) Above the ozone layer, the temperature starts to decrease again and reaches freezing temperatures at the lower limits of the ionosphere 27°F. *(-3°C.)*.

(4) The temperature increases throughout the ionosphere to reach its maximum constant value of 4,000°F. *(2,205°C.)* in the exosphere. The extremely high temperature existing at these altitudes is due to solar radiation. This extremely high temperature is insignificant in connection with air travel at this level, since it is the temperature of the infinitely small number of particles of air which exist on this level, and there is virtually no heat control or conduction. Heat transfer at or above this level is entirely by radiation.

F. Radiation

(1) Solar radiation - visible light, ultra-violet, infra-red.

(a) *Visible light.* In the dense lower layers of the atmosphere visible radiation or light is scattered by air molecules, dust, and water vapour, producing a variety of sky colours, the most typical of which is the light blue daylight. This bright light obscures the stars and the moon. The light which concerns the flyer is the light that reaches the earth and the highest altitudes to which man can fly.

(b) *Ultra-violet radiation.* This is ordinarily absorbed by dust, water vapour and ozone. Ultra-violet radiation increases in intensity with altitude so that at 50,000 feet *(15,240 metres)* this may be two to eight times the radiation received at sea level. In the lower layers of the atmosphere we are in large degree protected from the harmful effects of the ultra-violet portion of solar radiation by the effective absorption properties of the atmosphere. This takes place in the ozone layer between 80,000 and 150,000 feet *(24,390 and 45,720 metres)*, so that very little ultra-violet radiation reaches the earth. Those of you who have suffered the discomfort of severe sunburn can perhaps imagine the damaging effects of full-intensity ultra-violet radiation such as might occur at these heights. The intensity of ultra-violet radiation at 50,000 feet *(15,240 metres)* does not seem to have harmful effects on aircrews over reasonably short periods.

(c) *Infra-red radiation.* This is the heating portion of solar radiation which gives the sun its warmth. With increase in altitude and a decrease in atmospheric absorption, the sun's rays get hotter, causing heating of the body, clothing and aircraft surfaces facing the sun.

(2) *Cosmic radiation.* This radiation is much more penetrating than other forms of radiation such as sunlight and ultra-violet radiation. In the lower altitudes we are protected from the damaging effects of most of the cosmic radiation by the filtering effect of the atmosphere, a shielding influence equal to 37 inches *(94 cms)* of lead. There is a maximum of cosmic radiation between 60,000 and 80,000 feet *(18,288 and 24,384 metres)*. The intensity decreases with decreasing altitude so that at sea level it is about one seventieth of that at 70,000 feet *(21,336 metres)*. The data obtained from earth satellites indicate the existence of another layer of dense radiation about 1,000 miles *(1,610 kilometres)* above the earth's surface at the equator and at a greater distance above the earth's surface at higher latitudes. The intensity of radiation is greater at the poles because the earth's magnetic field attracts charged particles to its poles. Cosmic radiation, unlike solar radiation, is made up of primary particles, e.g., protons, neutrons, alpha particles, and heavy nuclei, travelling from space at speeds approaching that of light and capable of causing microscopic tissue damage. However, in the levels of the atmosphere between 80,000 and 120,000 feet *(24,384 and 36,576 metres)* the particles collide with air molecules and atomic nuclei, producing showers of secondary rays which penetrate into the lower atmosphere but with much less energy and tissue damaging effect than the primary space rays. At the levels at which we can now operate, i.e., sea level to 100,000 feet *(30,480 metres)*, the increase in cosmic radiation does not create a serious hazard to the flyer for the short periods it is possible to remain at these altitudes.

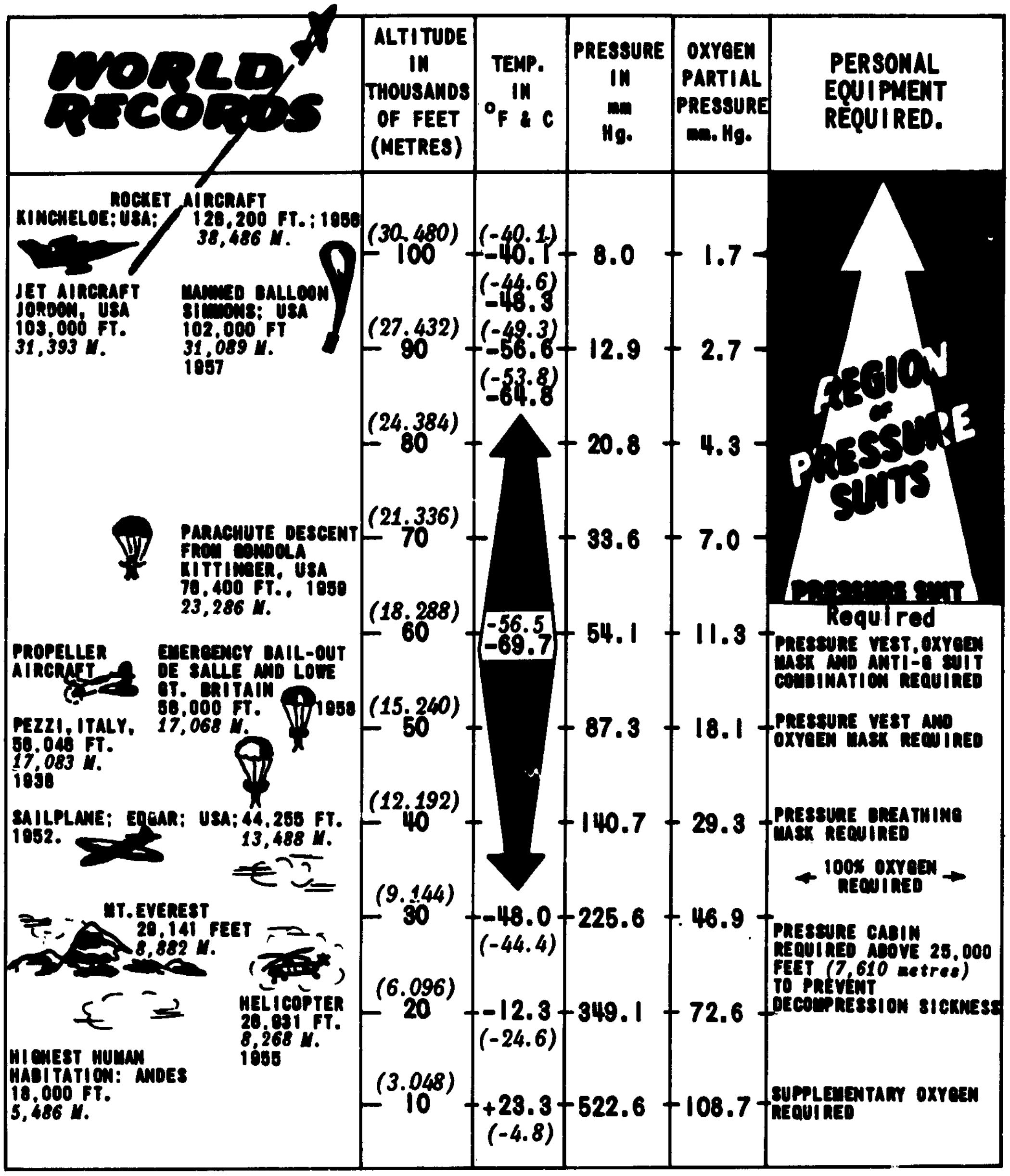


Fig. 5 Characteristics of the atmosphere and oxygen requirements

CHAPTER 4

HYPOXIA

A. Definition

Hypoxia is defined as a state of inadequate oxygen supply to the tissues. Anoxia means total oxygen lack but is often used loosely to mean hypoxia.

B. Historical

(1) From the earliest times, we have records of man baffled by his failure to climb far above sea level. The climber became weak, panted for breath, was plagued by vomiting, cramps and hallucinations - and sometimes died. It was a strange and frightening disease and went simply by the name of Mountain Sickness.

(2) As man became more sophisticated, the explanations for Mountain Sickness became more scientific. It was soon realized that the fall in atmospheric pressure with altitude played a key, but confusing part in the illness. In 1875 a balloon carrying three Frenchmen dramatically illustrated the peril. The only survivor wrote: 'I now come to the fateful moment when we were overcome by the terrible action of reduced pressure. At 23,000 feet *(7,010 metres)* torpor had seized me. I wrote, nevertheless - though I have no recollection of writing. We are rising. Croce is panting. Sivel shuts his eyes. Croce has also shut his eyes. At 24,000 feet *(7,315 metres)* the torpor that overcomes one is extraordinary. Body and mind become feebler. There is no suffering. On the contrary, one feels an inward joy. There is no thought of the dangerous position; one rises, glad to be rising. I soon felt myself so weak that I could not turn my head to look at my companions. I wished to call out that we are now at 26,000 feet *(7,921 metres)* but my tongue was paralyzed. All at once I shut my eyes and fell down powerless and lost all memory.'

(3) This perfectly illustrates the fatal rapture of altitude - two men dying and the other writing 'one rises, glad to be rising'.

(4) At the end of the nineteenth century, the true mechanism of hypoxia was recognized. Research in prevention still continues.

C. Mechanism of Oxygen Transfer

(1) When we breathe in we draw air down through a multitude of small tubes (bronchi) into the thin-walled microscopic air sacs (alveoli) of the lung. Flowing round these air sacs is the blood returning from the tissues, where most of the oxygen was removed and the waste gas carbon dioxide (CO_2) added. In the air sacs this 'venous' blood is replenished with oxygen and the carbon dioxide is removed to become 'arterial' blood. This gas exchange is a purely physical process depending on the relative pressures of the gases in the air sacs and in the blood. In sea level air the partial pressure of oxygen is $760 \times \frac{21}{100}$ or 160 mm mercury. (See Chapter 3.)

(2) By the time it reaches the air sacs, because of mixing with water vapour and outgoing carbon dioxide, this pressure is rather lower - about 100 mm Hg. The pressure of oxygen in the venous blood varies slightly, but is usually around 40 mm of mercury. Therefore, there is a pressure gradient of 100 minus 40 or 60 mm of mercury forcing oxygen into the blood. As a result, the blood is nearly 100 per cent saturated with oxygen at sea level. Atmospheric pressure decreases with ascent, and therefore the oxygen pressure falls and the blood is not so fully saturated. Below 10,000 feet *(3,040 metres)* the fall in saturation is slight but above this altitude it falls off rapidly so that less oxygen is picked up by the blood and carried to the tissues. THEREFORE, SUPPLEMENTARY OXYGEN IS REQUIRED AT ALL TIMES ABOVE 10,000 FEET *(3,040 metres)*.

(3) With sudden exposure to very high altitude, the unprotected body actually gives up oxygen to the air as the pressure gradient is reversed.

(4) These are inevitable laws of physics. The aim of all oxygen equipment is to maintain the pressure gradient of oxygen at, or as near as possible to sea-level conditions.

D. Effects of Hypoxia or Oxygen Lack

Failure to maintain this pressure gradient leads to inadequate delivery of oxygen to the tissues.

(a) The body has no store of oxygen, and although some organs can function for a short time without oxygen, this is not true of the brain. The brain is critically dependent upon a large and constant supply of oxygen. Most early symptoms of hypoxia are therefore manifestations of interference with brain function. Furthermore, it is the more highly specialized brain functions which suffer first. Judgement becomes defective, calculations are inaccurate, appreciation of time is lost, and sometimes there are marked changes in mood, i.e. pugnacity, hilarity, sleepiness, or false self-confidence. Unconsciousness and eventually death follow. The great danger of hypoxia is the inability to recognize the trouble and carry out corrective procedures. Many people have been mildly hypoxic while flying and have not been aware of it. Some of these have crashed. The ability to recognize hypoxia depends upon the altitude. Above 40,000 feet *(12,192 metres)* the onset of hypoxia is so rapid that it is stunning. Conversely, at low altitude it is so slow that it is imperceptible. Most hypoxia incidents in aircraft are in the latter category, e.g. a leaky mask in a partially pressurized cabin.

(b) The retina of the eye is sensitive to oxygen lack. By day, visual acuity is reduced by severe lack of oxygen. By night, even slight hypoxia may cause dangerous impairment of vision.

(c) In a hypoxic individual muscular contraction becomes weak, arms and legs feel heavy, and co-ordination of movements is poor. Writing becomes very difficult. With severe hypoxia uncontrollable tremors and twitching of the arms occur.

(d) Lack of oxygen interferes with the production of body heat, and the hands and feet feel cold. (Extra oxygen will not, however, prevent one from feeling cold if inadequately dressed.)

(e) Hypoxia predisposes to air sickness.

(f) In a hypoxic individual the rate and depth of breathing are increased. These may not be noticeable, but may give rise to a distressing air hunger. The danger here is that the sufferer will decide he is hyperventilating (see Chapter 5) and not realize the underlying cause.

(g) During hypoxia, the heart beats more rapidly and forcibly, and can be felt as palpitations of the chest.

(h) Hypoxia causes the lips and fingernails to become blue, but by the time you notice this you are useless.

E. Factors Increasing the Effects of Hypoxia

Several factors that will increase the effects of hypoxia are listed below:

(a) *Poor Physical Condition*. Poor physical condition caused by over-indulgence in alcohol, fatigue, illness, etc., will increase the effects of hypoxia.

(b) *Exercise*. During exercise, the oxygen requirements of the body are increased. This is especially important in aircraft in which the crews have to move around or do even slight physical work.

(c) *Smoking*. Every cigarette smoked leaves a certain amount of carbon monoxide in the blood. Carbon monoxide, even in minute quantities, reduces the amount of oxygen which can be carried by the blood, thus increasing the effects of any existing lack of oxygen.

(d) *Time at Altitude*. Effects will increase with time of exposure.

(e) *Rate of Ascent*. Effects of hypoxia are more severe during rapid ascents.

(f) *Frequency of Exposure*. Exposure to hypoxia several times a day will produce marked fatigue.

(g) *Cold or Excessive Heat*. Cold or excessive heat increases the body's requirement for oxygen and so increases the effects of oxygen lack.

F. Prevention

(1) *Methods*. There are two ways in which the oxygen pressure in the lungs can be maintained:

(a) by maintaining the pressure at or near to ground-level pressure; and

(b) by increasing the percentage of oxygen in the gas that is inhaled.

(2) *Pressure Cabins*. In passenger aircraft the pressure in the cabin is kept below 8,000 feet *(2,438 metres)* so that the passengers do not need supplementary oxygen. In combat aircraft this cannot be done because of the penalty to performance and the risk of cabin pressure failure (see Chapter 12). In these aircraft the cabin pressure is a compromise and kept below 27,000 feet *(8,230 metres)*, i.e. below the altitude where decompression sickness (bends) becomes a problem and where pressure breathing is required.

(3) *Supplementary Oxygen*. As you ascend using an oxygen system, the percentage of oxygen in the gas you breathe is automatically increased by the oxygen regulator. This is adequate until the atmospheric pressure has fallen to 140 mm of mercury (40,000 feet, or *12,192 metres*) at which point you will be breathing 100 per cent oxygen and will have an approximate 10,000 feet *(3,048 metres)* equivalent oxygen pressure in the lungs. Ascent above 40,000 feet *(12,192 metres)* will lead to a further fall in oxygen pressure comparable to the decrease in pressure on ascent to 10,000 feet *(3,048 metres)* breathing air. To avoid this, 'pressure breathing' is required to prevent hypoxia.

(4) *Pressure Breathing*. Essentially pressure makes the lungs into a pressure cabin by increasing the pressure above the atmospheric pressure. This means that if the atmospheric pressure falls another 10 mm of mercury the lung pressure must be increased by 10 mm by forcing the oxygen into the lungs under pressure. This is done automatically by the oxygen regulator. The pressure in the lungs is maintained by a tight-fitting oxygen mask with the exhalation valve 'compensated' so that it will not open until the pressure in the mask (and the lungs) is higher than the oxygen delivery pressure. This makes exhalation difficult (normally exhalation merely involves relaxation). The higher the altitude, the greater the pressure, and the more difficult it is to exhale. Mercury pressure is difficult to visualize, but many aircrews have experienced the Flack Test where they have to blow up a column of mercury. In this test, they have to hold up 40 mm of mercury for one minute and it is extremely tiring. To stay conscious at:

50,000 feet *(15,240 metres)*, you must breathe against 53 mm of mercury;
65,000 feet *(19,812 metres)*, you must breathe against 93 mm of mercury; and
100,000 feet *(30,480 metres)*, you must breathe against 132 mm of mercury.

In the altitude range 40,000 to 45,000 feet *(12,192 to 13,716 metres)*, pressure breathing is difficult but quite tolerable for short periods of time. It is therefore a strictly 'get-me-down' protection in an emergency following cabin pressure failure. Above 45,000 feet *(13,716 metres)*, where much higher breathing pressures would be required, it would take longer to get below pressure breathing altitudes and a standard A-13A mask is not adequate. Further protection, such as pressure suits, is required.

(5) *Partial-Pressure Suit*. Breathing very high pressures produces two basic problems:

(a) holding very high pressures in the lungs; and

(b) preventing the adverse effects of high pressure on the man.

These requirements are provided for by use of a garment or pressure suit which affords external body pressures in varying degrees, as required. A partial-pressure suit is so named because it only pressurizes part of the body. A full-pressure suit affords complete body pressurization. Nearly all the equipment designed to overcome these problems is a compromise between maintaining a physiological ideal and interfering with the pilot's normal function.

(6) *Above 50,000 feet (15,240 metres).* The A-13A mask is incapable of holding the pressure above 50,000 feet *(15,240 metres)* and becomes extremely uncomfortable, so a pressure head-piece is required. A pressure vest is also required to assist in breathing out. However, breathing at high pressures with these alone leads to unconsciousness within minutes. This is because blood trickling back to the heart from the extremities under very low pressure cannot enter the high-pressure region that has been created in the chest. To impel this blood back into the chest, some pressure has to be applied to it. In the Canadian suit, this is done with the 'G' suit inflated with oxygen to the same pressure as that in the head-piece. Some pooling of blood still occurs because the 'G' suit is not complete protection and the arms are not pressurized (deliberately, to allow the pilot mobility). This means that there is still a time restriction at very high altitude. This suit is designed as an emergency 'Get-you-down' suit if cabin pressure should fail. Further protection would restrict the pilot during normal operations, and impose a great heat load.

(7) *'Stay-up' Pressure Suits.* Stay-up capability after cabin pressure failure can best be achieved by the pilot in an impermeable pressurized garment, which is basically a form-fitting pressure cabin. This is a full-pressure suit. The following factors must be overcome in their design:

(a) there must be minimum interference with the pilot under normal flying conditions;

(b) he must be continually ventilated as he is totally enclosed in an impermeable garment; and

(c) when the suit inflates, mobility will obviously be restricted but this restriction must not interfere with the pilot's primary task.

Satisfactory suits are now in use, and when these suits are worn there is, theoretically, no limit to altitude or time at altitude, except in the supply of oxygen.

CHAPTER 5

HYPERVENTILATION

A. Physiology of Hyperventilation

(1) The nervous control of body functions is divided into two main types: one which is under your voluntary control, such as bending your elbow; and another type which is not, such as control of your heart beat. Functions which are not under your immediate control are usually concerned with the more automatic activities of your body.

(2) Since breathing is concerned with the supply of oxygen to, and the getting rid of carbon dioxide from, the body, it is rather surprising that it is not, like the heart, controlled by the automatic nervous system. Although breathing is normally automatic, we all know we can control our respiration at will. There is good reason for this. A controlled source of wind is useful to us for other purposes. Without it, for example, we could neither speak nor whistle as we work. This dual type of control of breathing, although very useful in our normal daily life, forms another one of the physiological mechanisms which can become vulnerable under the conditions of modern flight if we are not properly instructed on how to handle it. It represents a problem only to the unwary.

(3) Breathing more deeply than necessary - hyperventilation - may be just as undesirable as not breathing enough. Hyperventilation washes CO_2 out of the lungs (hence the blood and tissues) faster than it is being produced. CO_2 is carried in the blood as carbonic acid, so that hyperventilation inevitably lowers the acidity of the blood - a change to which the body objects. Because hyperventilation eventually interferes with the supply of oxygen to the brain, the symptoms this produces are very similar to those of hypoxia. This similarity makes self-diagnosis extremely difficult in an aircraft, particularly as one of the common symptoms of hypoxia is increased respiration. (See Chapter 4.)

(4) The impairment of brain function from hyperventilation is dangerous but, unlike hypoxia, it rarely leads to unconsciousness by itself, However, hyperventilation makes one very susceptible to other 'normal' stresses in flying. The shift in blood distribution that it produces is similar to the shift that occurs under positive 'G', with the result that the ability to tolerate positive 'G' is grossly reduced. After severe hyperventilation, even the 'G' pulled in rising from the lying to the standing position can cause blackout. (See Chapter 16.)

B. Causes of Hyperventilation

The causes of hyperventilation are as follows:

(a) *Emotion*. Fear, anger and excitement are all common to flying and all these increase your ventilation. To a pedestrian these emotions are preparatory to some action (flight or fight) which will produce extra carbon dioxide. The pilot's emotions are not followed by violent exertion so the increased ventilation is inappropriate.

(b) *Any Obstruction to Either Inhalation or Exhalation Could Lead to Overbreathing.* This could be caused by high or low flows from a faulty regulator; or high flow from an oxygen emergency bottle; or faulty oxygen mask valves. These situations may induce you to breathe heavily. With a little conscious effort overbreathing can be prevented.

(c) *Hypoxia.* Increased respiration normally occurs with hypoxia which, if noticed, may confuse the sufferer as to the cause of his symptoms. Hypoxia is urgent - make absolutely certain of your oxygen system before considering hyperventilation.

(d) *Pain.* This is usually due to change in gas volume, with changing atmospheric pressure, e.g. in the gut, ears or sinuses. Pain stimulates respiration.

C. How do You Know You Have Hyperventilation?

(1) Since the effects of hyperventilation and hypoxia are indistinguishable and constitute an emergency, you should assume that hypoxia from oxygen failure is the cause until proved otherwise. (See Chapter 6.)

(2) One of the earliest results from hyperventilation is a tingling in the hands and feet. This may be accompanied by a certain amount of giddiness. If the condition has progressed to a state where the blood supply to the brain has been significantly reduced, a sensation of air hunger may be present which, if acted upon, may lead to an accentuation of the condition. You may find yourself somewhat 'jumpy' and your hands tend to close up with your thumb in your palm. Hearing is reduced and there may be some interference of vision. You may feel faint and even confused. However, hyperventilation in itself is never the cause of pain.

(3) The severity of these symptoms will depend on how long or how deeply you have been hyperventilating. They also vary somewhat with different individuals - some being more sensitive than others. Most trained athletes are relatively resistant, but in a sensitive person, hyperventilation may finally lead to a complete loss of consciousness.

D. Treatment of Hyperventilation

(1) The best treatment for any condition is prevention.

(2) Moderate your breathing at all times. Check your mask and oxygen system before, during and after flight. If symptoms occur which might be due to hyperventilation, keep your breathing as normal as possible to allow the body's store of carbon dioxide to build up. Manual inflation of the 'G' suit will help to prevent the shift in blood distribution. (See Chapter 6 for complete emergency action.)

CHAPTER 6

EMERGENCY PROCEDURES

A. General

(1) Despite their many precautions, most experienced aircrews will admit to having undergone, on some occasions, physiological impairment while flying. Quite often these episodes are trivial, but impairment of any kind in an aircrew is always potentially dangerous. Incidents in the air may be caused by many widely different failures in the body such as hypoxia, hyperventilation, hypoglycaemia (low blood sugar), carbon monoxide poisoning, decompression sickness, etc. However, the ultimate effect is the same - impairment of brain function. Elaborate diagnostic and remedial procedures in these instances are impractical but corrective procedures are vitally necessary.

(2) During a physiological emergency, as at any other time, aircrews must remember to keep their breathing relaxed and normal in rate and depth. Their ability to offset or recover from any physiological disturbance is largely dependent on their inherent physical fitness and the simple ways in which they may avoid or control various environmental stresses such as temperature, radial or angular accelerations, decompression, postural immobility, etc.

(3) Their greatest hazard is hypoxia and the first emergency action must be diverted towards its correction, even though its presence is uncertain. The airman must decide primarily whether to stay on the aircraft oxygen system or pull the emergency oxygen bottle. The basic methods for preventing or correcting high-altitude hypoxia are well established and have been proved repeatedly. An adequate partial pressure of oxygen is maintained in the lungs by increasing the percentage of oxygen in the breathing mixture as aircraft cabin or cockpit pressure decreases with altitude. Above 38,000 feet *(11,582 metres)* cabin altitude, 100 per cent oxygen is not enough to provide an adequate lung partial pressure so the pressure of the breathing mixture has to be increased. This brings in the well known method of pressure breathing. To obtain adequate oxygen percentage and pressures, oxygen regulators are designed with automatic and manual percentage increases up to 100 per cent automatic pressure breathing deliveries, and manual and automatic safety pressures to counteract any leak in the delivery system. In the event of failure of the regulator, an emergency and bail-out oxygen bottle, capable of delivering 100 per cent oxygen under pressure, is provided. These fundamentals are theoretically adequate and normal or emergency oxygen actions compatible with them continue to be valid in practice.

(4) The oxygen problem, however, has been compounded with that of hyperventilation - over-breathing (see Chapter 5). This has been recognized as a complication among aircrews. It is attributable to apprehension of the high-performance aircraft environment, including the unnatural requirement of breathing through an oxygen face mask. It is more rarely attributable to the normal physiological response to hypoxia. The condition is a particular problem to an aircrew because of the similarity of its symptoms to those of hypoxia. In severe degree, hyperventilation can produce marked temporary disability or even fainting. It has been proved that an individual suffering

impairment from hyperventilation may not be able to correct his over-breathing even when exhorted to do so. For this reason, aircrews should always endeavour to maintain a normal rate and depth of breathing at all times when flying.

(5) Recent medical research has indicated that breath-holding, with the straining effect which accompanies it, or the inappropriate application of sustained pressure to the mask through use or abuse of the press-to-test button, through unscheduled pressure breathing from an oxygen regulator, or unnecessary use of the emergency oxygen bottle, could produce a fainting condition in healthy individuals. For this reason, the following practices should be discontinued:

(a) Breath-holding except when disconnected from the oxygen system; and

(b) Any sustained pressure to the mask other than when the use of emergency regulator pressure or the emergency oxygen bottle is indicated. In the past emergency oxygen action has included a breath-holding procedure along with the general procedure directed towards an oxygen-lack correction. This was intended to correct either hypoxia or hyperventilation since the subject cannot, as a rule, distinguish the symptoms of one from the other. A more effective procedure is outlined below. Emergency procedures have varied in detail and complexity with the result that some confusion may exist in the mind of an impaired subject as to the exact action to be taken, at a time when he is least able to make a complex decision. With a view to standardizing a corrective emergency procedure, below is a simple and effective means to combat any physiological impairment thought to be due to hypoxia or hyperventilation.

B. EMERGENCY PROCEDURE. To Be Taken in the Event of Hypoxia or Suspected Hypoxia at High Altitude.

IMMEDIATELY upon detecting any symptoms suspected as due to oxygen lack (at the very first sign of impairment or abnormality) take the following action:

(a) PRESS THE TEST BUTTON ON THE REGULATOR MOMENTARILY.

(i) IF *NO* PRESSURE IS FELT IN THE MASK - you are not getting oxygen (you are disconnected from the system or the oxygen supply has failed). *Pull the emergency oxygen bottle* - this should revive you rapidly - then look for the cause.

(ii) IF PRESSURE *IS* FELT IN THE MASK - your oxygen system is intact - you are getting oxygen. The impairment could be caused by a leaky mask. You should immediately:

- *select 100 per cent oxygen on the regulator;*

- *select safety pressure (if applicable); and*

- *tighten or hold mask to the face.*

(b) **DESCEND IMMEDIATELY TO A SAFE CABIN ALTITUDE (10,000 feet *(3,048 metres)* or less).**

(c) **BREATHE NORMALLY AT ALL TIMES.**

(d) **INFORM SOMEONE OF YOUR DIFFICULTY.**

(e) **AVOID PULLING 'G', EXTREME HEAD MOVEMENTS, HIGH CABIN TEMPERATURE, BREATH-HOLDING, OR STRAINING MANOEUVRES.**

C. Descend

(1) The fact that you are not performing normally indicates that you should not remain at altitude. The airman should, therefore, descend immediately to a safe cabin altitude, 10,000 feet *(3,048 metres)* or less. This will depend on weather, terrain, fuel, ATC clearance, etc., but every effort should be made to descend to a cabin altitude of at least 10,000 feet *(3,048 metres)*. The descent should be cautious and gentle because violent action could aggravate the existing impairment.

(2) If the symptoms disappear as a result of the descent or correction of the fault causing impairment, there might be a temptation to continue the flight. This should be avoided because a man who has lost or nearly lost consciousness is not performing normally. The decision regarding emergency or precautionary descent must be made by the pilot. While there may be operational or environmental factors which may justify remaining at high altitude if the emergency seems to be corrected, it is emphasized that, in nearly every case, the decision to descend to a cabin altitude of 10,000 feet *(3,048 metres)* or less and to discontinue the mission should be immediate and automatic. It is recognized that many aircrews are subject to recurrent momentary disturbance of consciousness or sensations due to causes such as acceleration. Individual experience and familiarity tend to rule out the emergency aspects of these episodes. It is strongly cautioned that unless the impairment is very brief and of definite known cause based on experience, the affected aircrew should immediately initiate emergency oxygen action, descend, and return to base as soon as operationally possible. It is important that the cause of your impairment be fully diagnosed, since somewhat similar changes can be produced by other factors such as carbon monoxide poisoning, fumes, or failure of certain gadgetry, such as your oxygen or 'G' suit systems, or even the fit of your personal equipment. On the other hand, your impairment may simply indicate an impending attack of influenza. *You should notify the tower so that a medical officer can be on hand to examine you as soon as you land.* Your symptoms may pass off very quickly, after which it might be difficult for your flight surgeon to make the essential diagnosis.

D. Summary

In summary the emergency procedure, in its simplicity, should be as follows:

(a) Press 'Test' button on the Regulator.

(i) If NO pressure felt – *pull emergency bottle;* or

(ii) if pressure felt – *switch to 100 per cent oxygen*

- *select SAFETY pressure*

- *tighten mask;*

(b) descend to a safe cabin altitude; and

(c) inform someone of your difficulty.

CHAPTER 7

ACCELERATION OR 'G'

A. General

(1) 'G' is one of the fundamentals of nature. Properly handled it can be fun, but ignored, it may prove deadly. Along with altitude and speed it is one of the dimensions of modern space travel.

(2) Your appreciation of 'G' should become instinctive so that you are never taken by surprise or never in doubt as to what your instantaneous reaction should be. Either you can learn about this interesting topic in the light of your experience by reading the following, thinking about it, and suitably applying what you have learned, or, alternatively, you may learn the hard way.

(3) Be smart; put your thinking cap on and have fun in the air. An active appreciation of 'G' is essential for the full enjoyment of modern flight.

B. Definition

(1) Acceleration or 'G' is best defined by describing how it arises and what it does.

(2) 'G' arises:

(a) from change in direction during constant motion; or

(b) from change in speed with constant direction; or

(c) from attraction between masses, e.g. gravity.

(3) 'G' acts by:

(a) determining the weight of a body; or

(b) determining how fast a body will increase (or decrease) in speed if it is free to move; or

(c) determining in what direction a body weighs or would fall.

(4) 'G' always has three dimensions:

(a) magnitude;

(b) direction; and

(c) duration.

(5) 'G' can arise from more than one of these sources at any one time. The resultant 'G' is fused insensibly so that only final acceleration acts in one direction at one instant. Gravity itself is thus partly due to the attraction of the earth, modified by 'G' due to rotation of the earth's surface. No one can tell the difference between these two sources of 'G' by their sensations about gravity. Similarly when a missile is in stable orbit, the negative 'G' due to the circular path about the earth just balances the 'G' due to the earth's gravitational field.

C. Measurement of Acceleration

(1) An acceleration equivalent in amount to that of gravity is used as the unit of acceleration. This unit is represented by the symbol 'G'.

(2) 'G' is measured by an instrument called an accelerometer, and since gravity is always acting, an accelerometer reads 1 'G' at rest or when travelling at constant speed in a straight (horizontal) line.

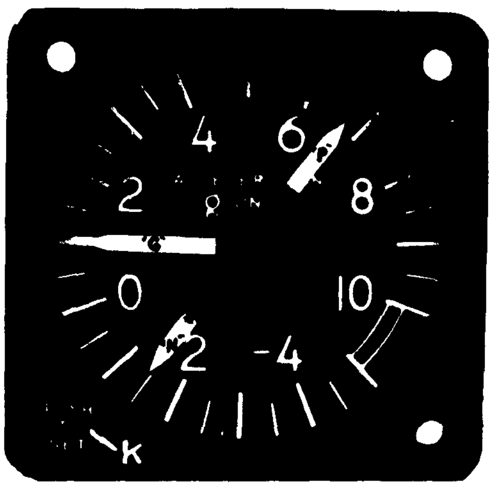


Fig.6 Accelerometer (Canadian)

(3) An accelerometer (Canadian) is illustrated in Figure 6. Two of the hands record respectively 'N', the maximum negative 'G', and 'P', the maximum positive 'G', encountered in a manoeuvre. The third hand 'G' continuously indicates the acceleration acting at any given movement. In the illustration, therefore, the aircraft is at rest or in level flight with the 'G' hand indicating 1 'G' due to gravity. The aircraft, however, has completed manoeuvres developing 1.5 'G' negative as shown by the 'N' hand, as well as 6.7 'G' positive as indicated by the 'P' hand. Hands 'N' and 'P' can be reset to equal 'G' by pushing the knob 'K'.

D. Examples - Acceleration Causing Weight

In a stationary elevator, a man holding his suitcases is held down by his weight resultant from the 'G' of gravity acting on his mass and the mass of his bags. As the

elevator ascends with increasing speed, an additional acceleration due to the change in speed is added to the 'G' of gravity. This increased 'G', acting on the man and his bags, makes them heavier. When the elevator reaches constant speed, the change in speed has disappeared and the 'G' again becomes the 1 'G' of gravity even though he is still moving (at constant speed). He then weighs his usual amount. When the speed is decreased as he reaches his floor, the direction of the resulting new linear 'G' is opposite and, therefore, subtracts from the 'G' of gravity. The net 'G' is less and, therefore, the man and his bags weigh less.

E. 'G' Causing Change in Speed

(1) If we drop a small coin, it increases in speed under the 'G' of gravity until it hit the floor. Any acceleration of 1 'G' acting freely causes a change in speed of 32 feet *(9.75 metres)* per second for every second it acts. If we drop a large coin at the same time as the small one, they both will hit the floor at the same time. Yet the large coin may weigh 10 times as much as the small coin. The reason for this behaviour is that the 'G' acting on both the coins is the same. They therefore accelerate at the same rate even though the force exerted by the large coin is greater than that of the smaller one. Gravity is thus not a force but is an acceleration or 'G'.

(2) A force is produced whenever a 'G' acts on a mass. This force is proportional in amount to both the 'G' and to the mass, i.e. force equals mass times the 'G'. Thus the small coin and the large coin accelerate at the same rate when under the same 'G' but the force they exert differs, since force depends not only on 'G' but also on mass. A pound of feathers weighs the same as a pound of lead, i.e. under constant 'G' the force exerted is proportional to the mass.

F. In Flight - 'G' Arises in Three Ways

(1) When in flight, 'G' arises in the following ways:

(a) from gravity which is essentially constant and always acting;

(b) from change in direction of flight - this may be in any direction, e.g., turn, loop, pull-out, or levelling off when coming in to land and is called centrifugal 'G'; and

(c) from change in speed - this is called linear 'G' and occurs

(i) during increasing speed of take-off - it is particularly noticeable in catapult or jet-assisted take-offs, also in seat ejections, and

(ii) during decreasing speed as in deck landings, braking, ditchings, etc, also in parachute openings and in parachute landings.

(2) The centrifugal 'G' lasts only as long as the change of direction of motion lasts. Similarly, the linear 'G' lasts only as long as there is a change in speed in any one direction.

G. Centrifugal 'G'

(1) Centrifugal 'G' is the type of acceleration experienced in any departure from flight in a straight line, be it upwards, downwards, or to the side. We are all familiar with centrifugal 'G'. For example, when swinging a pail of water, this 'G', acting on the mass of water, develops force which keeps it from spilling.

(2) During a turn in flight, the amount of centrifugal 'G' depends upon:

(a) the true air speed during the turn; and

(b) the radius of the circle in which the aircraft is changing direction

(3) Centrifugal 'G' varies directly as the square of the true air speed and inversely as the radius of the turn. For example, a turn, developing 2 'G' (centrifugal) at 200 knots, develops 8 'G' (centrifugal) at 400 knots, assuming the radius of the turn to remain the same. Similarly, tightening a turn, so that the radius is halved, doubles the centrifugal 'G' if the speed remains constant.

(4) The length of time required to complete a given turn varies directly with the velocity and inversely with the centrifugal 'G'. Thus a 180 degree turn at 3 'G' requires about 11 seconds to complete at 200 knots, but at 400 knots it requires 22 seconds, the 'G' being constant. Doubling the speed thus doubles the time required to complete the turn. On the other hand, if the centrifugal 'G' can be increased twofold, the time to complete the turn is reduced to half. The 400 knot turn at 6 'G' therefore requires the same time to complete as the 200 knot at 3 centrifugal 'G'. In turning you save time by increasing the 'G'.

H. Linear 'G'

(1) Linear 'G' is the type experienced, for exampl , when aircraft are accelerated or decelerated by a change of speed only. It arises in take-off and landing, in ejection seats when abandoning aircraft, during parachute openings, or in parachute landings. It is greater if the rate of change of speed is greater and thus is increased in assisted take-offs, and is particularly large during ditchings or crash landings when the speed change is very high.

(2) The amount of linear 'G' depends upon the following:

(a) *The amount of change in speed.* In ditchings, since the final velocity is zero, the linear 'G' varies with the speed of the aircraft at the time of impact. The higher this speed the greater the 'G'. In fact, the average linear 'G' varies with the square of this impact velocity.

(b) *The distance over which the change in speed is spread.* The shorter the distance the higher the 'G', other things being equal. It was linear 'G' that was experienced in our example of the man in the elevator.

(3) If, during a ditching, the speed of the aircraft on striking the water can be reduced from 100 knots to 75 knots, the 'G' acting on the crew will be cut approximately

to half (75^2 *vs.* 100^2). Similarly, if the deceleration can be spread over 50 yards *(45.7 metres)* instead of 10 yards *(9.1 metres)*, the linear 'G' will be reduced to one-fifth. Thus the difference in linear 'G' between ditching at 100 knots over a distance of 10 yards *(9.1 metres)* is tenfold what it would be on coming in at 75 knots and spreading the deceleration over 50 yards *(45.7 metres)*, i.e. (1/2 × 1/5).

(4) The direction of linear 'G' depends upon:

(a) the direction of the change in speed; or

(b) whether the speed is increasing or decreasing.

(5) In assisted take-offs, therefore, the speed is increasing in the direction of flight and the 'G' acts to force your body back into the seat. Conversely, during ditchings, the speed is decreasing and the 'G' now acts to force you forward into the harness. During seat ejection the direction is at right angles to these.

(6) The length of time the linear 'G' acts depends upon the average velocity during the deceleration and the distance over which the deceleration (or acceleration) is spread. In our previous example, in the ditching at 75 knots spread over 50 yards *(45.7 metres)*, the 'G' lasts for about 2.4 seconds, while in the ditching at 100 knots spread over 10 yards *(9.1 metres)* the 'G' lasts for only 0.35 seconds.

I. General Effects of 'G'

(1) The effects of any 'G' are determined by a combination of three factors:

(a) the direction it acts with respect to the aircraft or the body;

(b) its magnitude - the force varies directly with the 'G'; and

(c) its duration - momentarily large 'Gs' may be of little consequence - conversely, gravity acts continuously - but between these extremes the duration of the 'G' may be all-important.

(2) In Figure 6 the accelerometer records a maximum of 1.5 'G' negative and 6.7 'G' positive. This may simply have been encountered during a very bumpy landing. On the other hand, it may record a violent 2.5 'G' nose-over (from +1 to -1.5) followed by a tight spiral dive developing 6.7 'G' positive lasting for 30,000 feet *(9,144 metres)*. The time factor can make a difference.

J. Effect of 'G' on Aircraft

(1) An aircraft developing a total of 2 'G' during a turn weighs twice as much as it does in level flight. Similarly, at 4 'G' it weighs four times as much. While it lasts, this increase in 'weight' is just as real as increase in weight due to increased load (mass). The wing loading is increased, consequently the stalling speed is increased during any change in direction of flight which results in increased 'G'. This factor can be of vital importance to you. For example, if you have engine trouble during flight, don't forget that turning increases the weight of your aircraft at a time when it is already embarrassed. The weight of your aircraft depends equally on

the 'G' and the load. The use of the term 'all up weight' is a figure of speech - what is actually meant is 'all up mass'.

(2) It requires more work to turn, i.e., fly the increased weight. This extra energy inevitably must be provided by:

(a) loss of altitude (potential energy); or

(b) loss of speed (kinetic energy); or

(c) opening the throttle (maintaining kinetic energy).

(3) In loss of altitude, look out for the ground; in loss of speed, look out for a stall.

(4) Aircraft are designed to withstand various amounts of 'G' depending on their functional role. A fighter aircraft is more highly stressed than a transport aircraft. If the limited design 'G' is exceeded, structural failure may follow, e.g., bending or breaking off of wings.

K. Linear 'G' - Effects on Aircraft

Loose objects in the aircraft are thrown towards the nose in deceleration and slip to the rear in acceleration. If the amount of 'G' is great enough, supporting structures, such as retaining straps, may be broken and passenger seats wrenched from their moorings. In crashes, the heavier parts of the aircraft, e.g. engines, tend to break loose and continue in the line of deceleration after the lighter parts have come to rest. Don't forget that under 20 'G' a one-hundred pound mass weighs a ton *(50 kg)*.

L. Effects on the Body - Centrifugal 'G'

(1) The effects of centrifugal 'G' on an aircrew are determined by:

(a) the amount of 'G';

(b) the length of time it lasts; and

(c) the attitude of the body relative to the direction of the 'G'.

(2) In assessing 'G' of any turn, all three of these dimensions must be taken into consideration.

(3) By common usage, 'G', which pushes the airman down into his seat, i.e. acts from head to feet, is known as 'positive G'; conversely, 'G' acting from feet to head is called 'negative G'. (See Figure 7.)

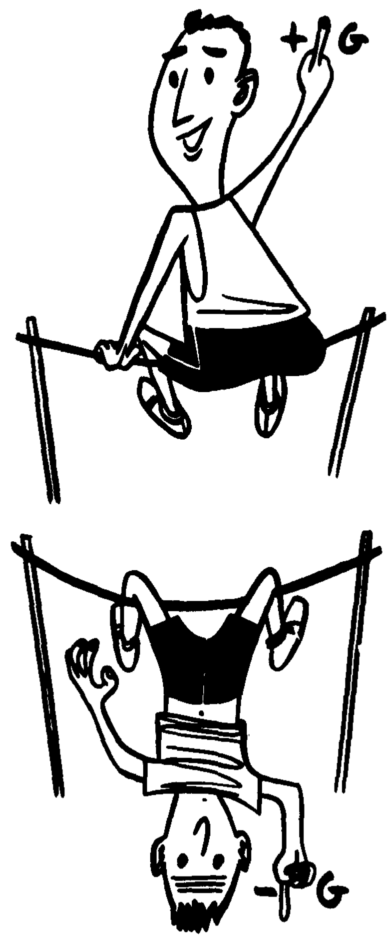


Fig.7 "Positive and Negative 'G'"

M. Positive 'G' - General Effects on the Body

(1) The 1 'G' of gravity offers no problem to the healthy man, but don't forget that, if for any reason one feels faint, one normally lies down and thus gets rid of most of the 1 'G' effect. This you cannot do when strapped upright in a cockpit. Manually inflating your 'G' suit to 'comfortable' levels under these conditions can be equivalent to lying down and may be as rewarding under the circumstances. Modulating this pressure may be even more effective (see Chapter 16). Knowing where your 'G' valve is located should be part of your instinctive cockpit drill.

Fig. 8 The Pause that Refreshes

(2) Increased positive 'G' is normally encountered in an inside turn. Properly seated, you first notice the effect of increased 'G' by your whole body becoming heavier. Under 2 'G' you are pressed more firmly into the seat - at 3 to 4 'G' this effect is more striking, and upward movement of the limbs becomes difficult or impossible. This lack of freedom of limb movement may be important in bailing out under high 'G'. Remember that movement transverse to 'G' is not so markedly interfered with, and you can often crawl or roll, therefore, when you cannot walk.

(3) It is really surprising how much increased 'G' the body can withstand without structural damage, when properly supported. A man with a normal mass of 160 pounds weighs half a ton under 6 'G', but, seated in his aircraft with harness properly adjusted, this load normally produces no structural damage unless he falls forward during the 'G'.

N. Effects on Circulation

In contrast to the lack of structural changes, increased 'G' always has some significant influence on the vital circulation system of the body. Under positive 'G', the blood supply to the brain is interfered with to a varying degree depending on the size of the 'G', the length of time it acts, and the length of the blood column in the direction of the 'G', i.e. your attitude in the aircraft. The initial effects of diminished blood supply to the head are similar to the effects of mild hypoxia. The first sensation may be one of euphoria, and memory may be subtly affected. Over a period of time, the net hangover effect is one of fatigue. Interference with blood supply to the head makes accurate split-second judgement more difficult. The brain has only a slight natural reserve and is thus dependent on the second-to-second supply of blood containing adequate amounts of oxygen and food. The first effect of decreased blood flow to 'G' is noticed in higher centres of the brain, and is thus apt to manifest itself as a loss of good airmanship in the unprotected or unwary. Under 4 'G' lasting for five seconds, this interference with circulation becomes so great that more

noticeable events occur, the first of which is an increasing interference with vision. This is called 'grey-out' and commences at the periphery of our field of vision. If the acceleration is increased to 5 'G', for five seconds, the average pilot will experience complete loss of vision or 'black-out', when normally seated. (See Figure 9).

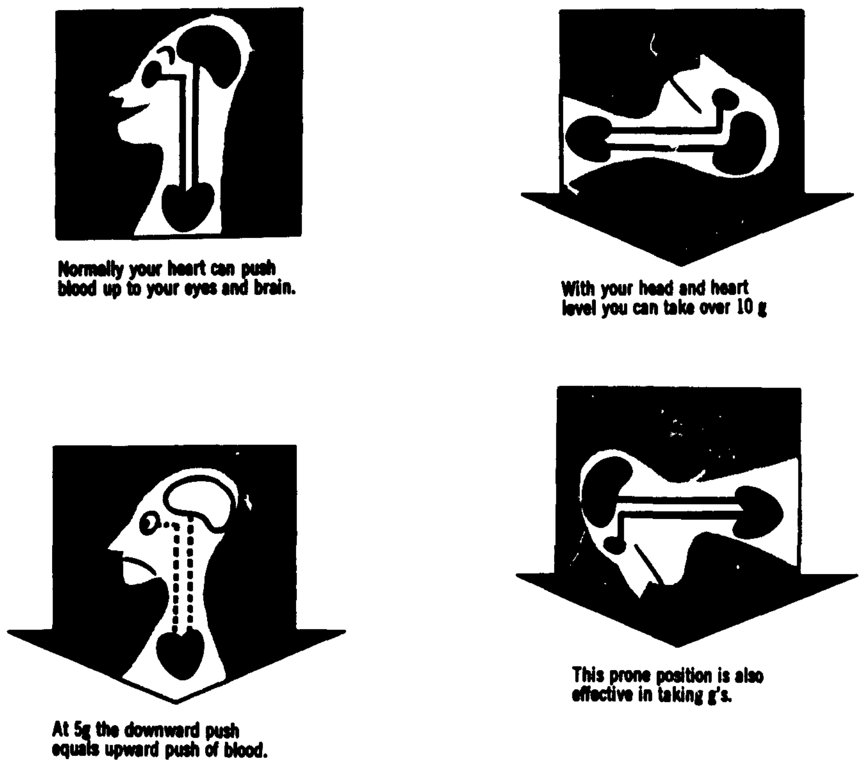


Fig. 9 Blood and 'G'

O. Time Relation

The interference with blood supply takes a few seconds to become noticeable, due to the simple inherent reserves in the brain. As a result, black-out is delayed for a few seconds after the commencement of the turn. Similarly, these events persist for a short while after the return to normal 'G', particularly the confusion, if consciousness has been clouded. This is a good time to shake yourself out of it and wake up fast.

P. Tolerance to Positive 'G'

(1) The 'G' tolerance of various individuals varies considerably, and it is important that you are aware of your own tolerance. Remember, 'G' tolerance does not correlate with either intelligence or intestinal fortitude.

(2) Your 'G' tolerance can also vary from day to day and it usually improves about half a 'G' during training. Controllable factors affecting it are as follows:

(a) *State of Health.* Your 'G' tolerance can be seriously reduced by influences such as illness, excessive hot weather if your salt intake is not maintained, flying on an empty stomach, dehydration from any cause, excessive use of alcohol, or poor physical condition generally. Your flight surgeon can advise you on these points.

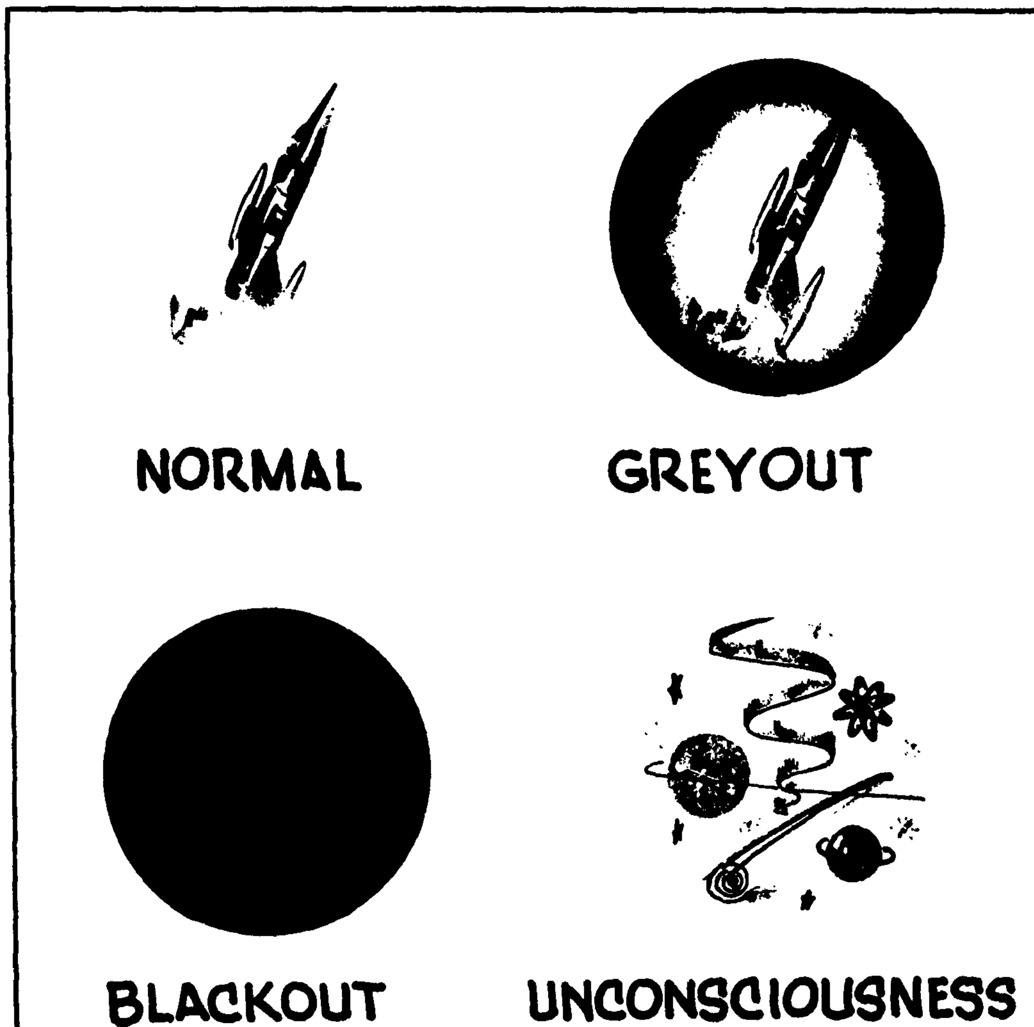


Fig. 10 Positive 'G' Effects

(b) *Attitudes in Aircraft.* Since the chief effect of 'G' is on your blood circulation, the resulting pressure changes can be reduced if the main blood vessels are shortened in, or angled to, the direction of 'G' (Fig. 11). Raising your feet and lowering your seat thus decrease your

height in the direction of the 'G' and increase your tolerance, particularly if you tense your muscles at the same time.

(c) *Straining Manoeuvres.* 'G' tolerance can be raised slightly for short periods by tensing the chest and abdomen and exhaling through partly closed vocal cords so as to produce a sound as loud humming or yelling. This forced exhalation should be repeated frequently (i.e. every 3 to 4 seconds) while under 'G' but is not effective for more than about 10 to 15 seconds unless wearing a 'G' suit.

(d) *Anti-'G' Suits.* The net effect of increased pressure in the columns of blood from increased 'G' is twofold. Firstly, the heart must do more work if the blood is to be pumped to the head. Secondly, the increased pressure distends the elastic blood vessels in the lower part of the body, particularly the veins. The blood thus tends to pool in the legs and belly, with the result that the return blood supply to the heart is decreased at a time when we are asking the pump to do more work. If however, during the increased 'G', an increased fluid pressure is brought to bear against the walls of the blood vessels, these 'G' changes can be prevented. The level of a cork floating in a pail of water does not change, therefore, when it is swung, even though the cork becomes heavier, because of the increased buoyancy from the increased weight of the water. The 'G' effect is thus balanced out. These principles have been applied in the 'G' suit which protects you against positive 'G'. In the first suit made in Canada in 1939, the balancing pressure included the whole body with increased pressure on the lungs to protect the heart. It soon became evident that, for the 'G' encountered in present-day aircraft, it was sufficient simply to assure the return of the blood to the heart - the pump's reserve being able to take care of the increased load. For the present, therefore, 'G' suits apply pressure only up to heart level.

(e) *How Fluid Pressure is Supplied by Your 'G' Suit.* The proper fluid pressure to your body is supplied by your 'G' suit through a combination of three mechanisms:

(i) A 'G' valve affixed to the aircraft supplies air to the suit under pressure in proportion to the 'G' developed. It has two settings, 'high' or 'low' according to your personal needs. The pressure does not come on until approximately 2 'G' is reached. The 'G' valve also has a button which, when pressed, will inflate the suit manually. This is useful in long flights under 1 'G' when you remain seated in one position - its effect is somewhat equivalent to getting up and walking around.

(ii) Your 'G' suit is interlined with thin-walled bladders over parts of your body. These, when inflated with air from the 'G' valve, produce the correct balancing pressure against your body.

(iii) Areas of the body which are not covered by the bladder get their proper pressure from tension built up in the inextensible fabric of the suit. How effective this is depends on how accurately your suit is fitted. This fitting is accomplished by proper sizing and proper adjustment of the lacing within the suit itself. The suit is thus like a pair of shoes - it fits even better after some wear and may require further adjustment. While your suit takes care of the return of blood to the heart, the vital pressure developed by the heart pump can be further assisted by the straining manoeuvre. Since your suit is activated at all 'G's' over 2, its most common use is in preventing the mild brain hypoxia and fatigue associated with 'G' below black-out level. Like a parachute, it is also nice to have when needed more acutely.

When you become accustomed to your 'G' suit, you unconsciously come to rely on its support during turns. If, for any reason, you have left it at home, therefore, be sure to tense yourself under 'G' otherwise you may find your (unprotected) tolerance is lowered somewhat because of unconscious relaxation.

(f) *Prone or Supine Position.* Research has been in progress for several years on placing the pilot in the prone or supine position. The advantage of this is that centrifugal 'G' is then acting transversely to the body, so that the blood does not drain from the brain nor pool in the extremities (Fig.11). This will be of importance in the very high accelerations of rocket and space travel.

Q. Negative 'G'

(1) In negative 'G', the 'G' is acting from the feet towards the head, and it is encountered in a small degree in nosing over from level flight, or during inverted flight, or more seriously in outside loops. The blood in negative 'G' tends to drain towards the head, and causes the face and eyes to become suffused, giving a gritty sensation to the eyes. If the negative 'G' is prolonged, vision becomes dimmed by a red haze or 'red-out'. Negative 'G' is unpleasant, swallowing is difficult, and the increased pressure in the blood vessels to your brain leads to confusion.

(2) Negative 'G' should be avoided where possible, but some tolerance can be developed by graded practice. Your present 'G' suit is not designed to help against negative 'G'.

R. 'G' as a Limiting Factor in Flight

If you are travelling in a given direction at a given speed and it is essential that you turn in relation to a given point (e.g. with ground or a target), then the 'G' you are able to handle (both with your aircraft and with yourself) is one of the inevitable dimensions in the situation. For example, if the weather should close in while you are travelling at 400 knots and you suddenly find yourself breaking cloud at 60 degrees (Fig.12), then you will get away with it at altitudes down to 1400 feet *(427 metres)* if you can handle 7 'G', but only down to 2000 feet *(610 metres)* if you can handle only 5 'G'. There is no time to go back and get your 'G' suit.

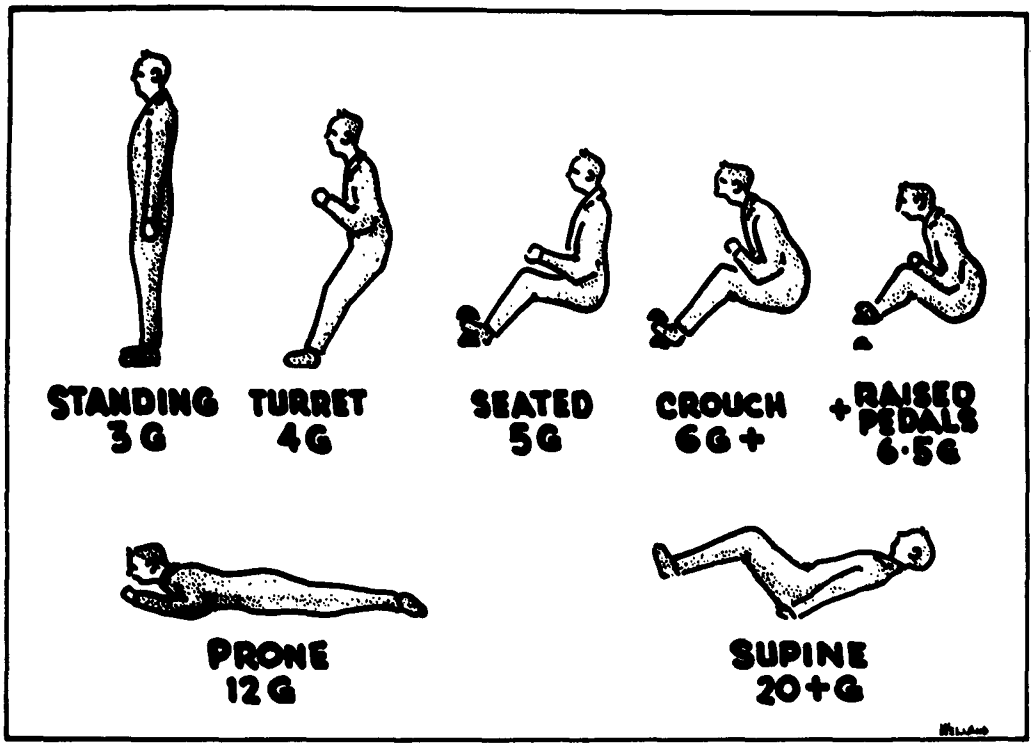


Fig.11 Influence of body attitude on tolerance to 'G' lasting for 5 seconds

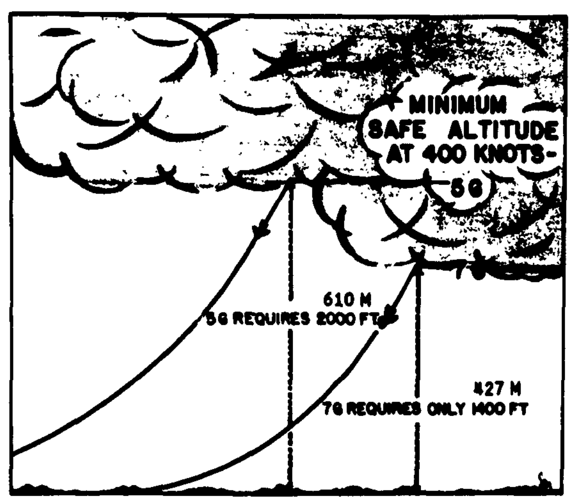


Fig.12 Breaking cloud

S. Effects of Linear 'G' on your Body

(1) The effects of linear 'G' on your body depend upon:

(a) the pressure per unit area developed against your body by the resulting force;

(b) the rate the 'G' develops; and

(c) the length of time it lasts (i.e. the distance through which it acts).

(2) The unit pressure developed as a result of a given 'G' depends upon:

(a) *the size of the 'G'* - anything that will reduce the 'G' will reduce the pressure; and

(b) *the area over which the force is borne* - if the area is great, the unit pressure is low; increasing the area ten times reduces the unit pressure to 1/10.

(3) As we have seen, the 'G' can be reduced by decreasing the speed to a minimum (don't forget you are repaid as the square), and by spreading the 'G' over as great a distance as possible. During ditching, the area over which the force can be borne is increased by your crash helmet and by your harness. For example, if, on striking your head, your helmet spreads the load over 50 square centimetres instead of 1 square centimetre and allows the resulting force to act through 1 centimetre instead of 1/10 centimetre, the resulting unit pressure is reduced 500 times (50 × 10).

(4) If the 'G' develops very rapidly, a pressure wave is set up through the body which may have undesirable effects. The rate of discharge of your ejection seat is thus controlled to give a 'G' change which the body can withstand when properly supported in the seat.

(5) In parachute landings, the distance over which the 'G' acts can be increased by suitably tumbling on hitting the ground, and the area over which the force is borne is also increased by this manoeuvre.

(6) The amount of linear 'G' the body can tolerate is enormously high, if properly handled. The energy dissipated through your body in a ditching at 300 knots is no greater than that encountered in a hot bath. Modern aircrews know how to handle high deceleration - by decreasing the impact speed, increasing the deceleration distance, and increasing the supporting area.

T. Practical Points for Aircrews

(1) *Buffeting (at Low Altitude)*

(a) Sudden changes in 'G' or rate of change of 'G' (jolt) of a high order may be encountered during rapid flight in rough air, particularly over uneven terrain at low altitude.

(b) This may have certain physiological effects, including the following:

(i) Momentary changes in vision - it is hard not to blink during a bump.

(ii) Actual damage from striking the body, particularly the head. Adjust your harness to minimize undesirable bouncing about, and wear your helmet to protect your head.

(c) Prevention has its role here. The avoidance of these conditions depends on a knowledge of their cause and the application of good airmanship in the light of this knowledge.

(2) During deceleration, the whole body is thrown forward on the harness, and the head, being unsupported transversely, tends to 'whip' forward on the neck. If the shoulder-straps are not tight, the head may hit the front of the cockpit, fracturing the skull. If the lap-strap is not tight, the lower part of the body tends to slip through below it, causing severe internal injuries.

(3) In multi-seat aircraft, the passengers tend to be thrown forward and should, therefore, be tightly strapped in if in transport aircraft, or in crash positions in other aircraft. They should sit facing rearwards with the back and head firmly pressed against a strong malleable structure, e.g. a bulkhead. In this position they will withstand the impact 'G' best, since it is distributed over the greatest area and through the greatest distance. This is the basis for the installation of rearward facing seats on transport aircraft. All loose or loosely supported objects in the aircraft should be firmly tied down, jettisoned, or brought forward in the event that a crash landing should become necessary, otherwise serious injury may result to occupants.

(4) *'G' and Other Stresses.* It has been seen that positive 'G' tends to reduce the vital blood supply to the brain. In flight this factor may be superimposed on other conditions which affect the brain, such as hyperventilation, hypoxia, hypoglycaemia, or feeling faint for any reason. Remember this and don't compound your troubles. At the same time, your 'G' suit manually inflated can be life-saving, if the airmanship of the situation demands that you undergo even a small increase in positive 'G'.

U. Practical Points for Harness Adjustment

(1) See that your shoulder-straps, with your harness in the locked position, are so tight that forward movement is restricted. If necessary, get the shoulder buckles adjusted before take-off.

(2) Tighten your lap-strap fully before tightening your shoulder-straps, otherwise you may slip through below.

(3) Always lock your harness for take-off and landing. If your harness is properly adjusted you should not be able to move forward. (See figure 13).

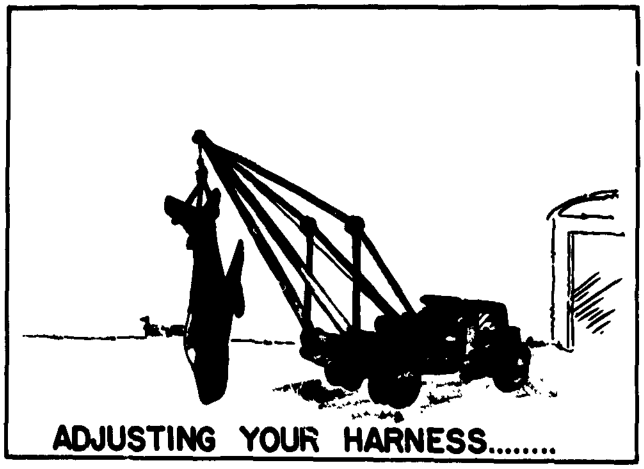


Fig. 13 Adjusting your harness

You adjust your harness to give you maximum support in this direction, that is, as you would if your aircraft were being held up by the tail.

V. Linear Acceleration of Aircraft

(1) Since, with increasing speed, the 'G' is acting transversely to the body, the pilot is merely forced back into the seat. The body can withstand 10 'G' lasting for 10 seconds in this direction, or more. This means an increase in speed of 10 × 32 feet per second per second which, lasting for 10 seconds, amounts to 3,200 feet per second *(980 metres per second)* or nearly 1,900 knots (Mach 3). If properly seated, therefore, there will be no limiting human factor in assisted take-offs for some time to come.

(2) Properly informed and properly protected with 'G' suit, harness and helmet, life at high speed in three dimensions can be safe and fun.

W. The Fusion of Accelerations from Various Sources

(1) As pointed out previously, 'G' can arise in any one of three different ways: i.e., from gravity, from change in speed, or from change in direction of flight. It is obvious that more than one of these factors may be acting at any one time and it is important to know how they interact.

(2) As noted previously, 'G' is always characterized by an amount and a direction and the following rules may be given:

(a) accelerations arising from various sources always fuse to give one single final 'G';

(b) various 'G's' fuse not only according to their amount but also according to their direction;

(c) this fusion is insensible and you cannot differentiate by your feelings, therefore, the part of gravity due to the attraction of the earth and the part due to our rotating on the earth's surface;

(d) similarly, your aircraft in flight is only influenced by the resultant 'G', irrespective of the sources of the various components; and

(e) the fusion to give the final resultant 'G' occurs according to the vectorial parallelogram of forces.

(3) In a horizontal turn developing 5 'G' centrifugal in normal gravitational field, the actual 'G' is shown in Figure 14. Furthermore, at the bottom of a pull-out from a dive, the 1 'G' of gravity and the centrifugal 'G' are both acting in the same direction. They, therefore, simply add to each other. Thus a 5 'G' (centrifugal) pull-out develops 5 plus 1 or 6 'G' at the bottom of the turn. Similarly, at the top of a 1 'G' centrifugal loop, the 1 'G' centrifugal is acting opposite to gravity; the effective 'G' thus becomes 0, i.e. +1 -1.

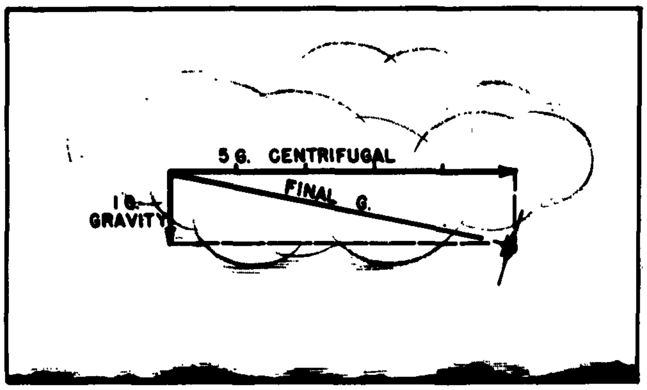


Fig.14 5 'G' Centrifugal - Horizontal turn

(4) Remember this also when adjusting your harness for ditching. During a 20 'G' ditching, the deceleration acts essentially directly forward. (See Figure 15).

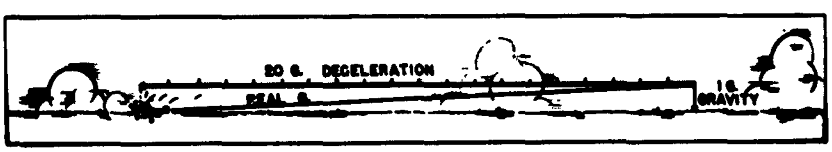


Fig.15 20 'G' Deceleration

X. 'G' Facts for the Mathematically Minded

(1) $$G = \frac{dv/dt}{g} = \frac{\text{change in velocity in feet per second per second}}{32}$$

(2) *Centrifugal 'G'*

(a) For computing the centrifugal 'G', the following formula may be found useful:

$$G = \frac{V^2}{11r}$$

where V = true air speed in knots,
r = radius of turn in feet.

(b) The time required to make a turn is important in tactics. It often pays to get there first. The time required to make a turn is reduced in direct proportion to the increase in 'G' developed. The higher the 'G' the faster the turn at a given speed. For example, a 6 'G' turn requires only half the time that a 3 'G' turn requires at the same speed. On the other hand, the faster the speed in a turn, the longer it takes. A 5 'G' turn at 400 knots requires twice the time to complete that a 5 'G' turn at 200 knots requires. This can be summed up with the simple formula:

$$T = \frac{KV}{G}$$

where T = time to complete a given turn in seconds,
V = true air speed in knots,
G = 'G' centrifugal,
K = constant depending on how big an angle the turn is,

K for 180° = about 0.17; for a 360° turn it is twice this.

(c) This is the fundamental formula of manoeuvring tactics, and it is evident that:

(i) the fastest way to turn is to lower the speed and pile on the 'G' (but beware of stall), and

(ii) the higher your 'G' tolerance, the tighter and faster your can turn.

Y. Linear 'G' Mathematics

(1) The 'G' built up under crash conditions may be very high and depends upon the following:

(a) The square of the initial velocity on landing.

(b) Inversely as the distance over which the deceleration takes place. Reducing the speed, therefore, from 150 knots to 75 knots at the

moment of impact reduces the 'G' to one-quarter. Likewise, 'breaking' the crash over a distance of 100 yards *(91.4 metres)* instead of 50 yards *(45.7 metres)* reduces the 'G' by half. The same rules apply to parachute landings.

(2) The 'G' built up by changes in speed is best described by the simplified formula as follows:

$$G = \frac{V_1^2 - V_2^2}{64d}$$

where V_1 = the speed in feet per second at the beginning of the change,
V_2 = the speed in feet per second at end of the change,
d = the distance in feet over which the change in speed takes place.

(3) During ditching this becomes simply:

$$G = \frac{V^2}{64d} \quad \text{(since } V_2 = 0 \text{ and } V = V_1\text{).}$$

(Remember that 100 knots is equivalent to 169 feet *(51.5 metres)* per second).

CHAPTER 8

ESCAPE FROM AIRCRAFT

A. General

(1) Abandoning an aircraft may become necessary, either while it is under control and ample time is available, or in an emergency when speed of exit is vital. If the drill laid down for flying personnel is closely adhered to, a happy ending to the emergency will follow, but this drill must be so completely understood and learned that it is instinctive and automatic when the emergency presents itself. This applies to both multi- and single-seated aircraft. At the same time, don't let repetition *ad nauseam* allow you to become dangerously blasé.

(2) Once the situation demands that you abandon an aircraft, your lusty 'drive' to survive should come into play. You should have made up your mind about this long beforehand as an essential part of the drill. Tolerate no blocks. Grit your teeth, get out, and get out fast.

B. Abandoning Aircraft at High Speeds

(1) Up to 130 knots IAS, it is possible to bail out of all aircraft without any special precautions, other than to allow sufficient clearance from the aircraft before opening the parachute, provided there is sufficient altitude for the parachute to deploy.

(2) Above 130 knots IAS, it is necessary for the body to be assisted out of the aircraft in order to clear the aircraft structure. There are two methods of assisting escape:

(a) use of gravity or 'G'-force, i.e. tumbling through a hatch in the floor or rolling the aircraft on its back, pushing the stick suddenly forward with harness straps, oxygen connections, etc., undone; and

(b) by ejection seat - an explosive catapult or rocket acts in such a way that both flyer and seat are ejected together.

(3) There are two major types of seat firing in use. In one type, the charge is fired by squeezing a trigger on the arm-rests. The other type is fired by pulling a blind down over the face; this type is also fitted with an alternative firing handle located between the knees.

(4) On most aircraft the canopy is jettisoned as part of the ejection sequence either by raising the arm-rest or by the initial movement of the face blind. If the canopy does not jettison, the seat and aviator will fire through the canopy. This is safe provided the person is properly positioned in the seat. On some aircraft it may still be necessary to jettison the canopy by a separate switch, prior to ejecting the seat.

(5) A peak acceleration of approximately 18 to 20 'G' is reached during ejection. This is well within the physiological tolerances for such a short duration and no injuries should result provided the person is correctly positioned, with the seat harness tight and locked. Feet should be in the stirrups or leg restraints attached, knees together, elbows in, and head back firmly on the head-rest. This acceleration results in an exit velocity sufficiently high to clear all aircraft structures as well as providing added height in the trajectory to permit more time for parachute deployment in level flight ejections near the ground.

(6) All ejection seats are now automatic in that seat harness release and parachute opening is done at the correct time and altitude. In some ejection seats the occupant is forcibly separated from the seat as part of the automatic sequence. In others, however, the seat occupant must exert deliberate physical effort to push the seat away from him before automatic parachute deployment can continue.

(7) In the latter type of seat it is important for the occupant to remember to get free of the seat as soon as possible after ejection and *not* to hang on to the seat handles in fear and confusion waiting for something to happen.

(8) In automatic ejection seats there are manual facilities provided for use in the event of failure of the automatic seat harness release and parachute deployment devices.

(9) At high speed adequate protection from wind-blast is provided by normal flying clothing, oxygen mask, and the visor in the down position.

C. Descent from High Altitudes

(1) Bail-out at altitudes where oxygen is required presents some special hazards as it will be necessary to delay opening the parachute until a lower altitude (approximately 15,000 feet, or *4,572 metres*) is reached to avoid the following:

(a) *Loss of Consciousness Through Oxygen Lack.* Below 30,000 feet *(9,144 metres)*, when leaving an aircraft without bail-out oxygen, a few deep breaths should be taken before disconnecting the supply and the breath should be held as long as possible before and after escape. In escapes above 30,000 feet *(9,144 metres)* a bail-out oxygen system is essential and is available with all ejection seats. On some seats a round green knob has to be pulled prior to ejecting; on other seats it may be turned on automatically by the seat leaving the aircraft. The oxygen supply is adequate for a free fall to a safe breathing altitude.

(b) *Excessive Parachute Opening Shock.* In addition to the danger of opening the parachute before the body has reached its terminal velocity at high altitudes, there is a danger of injuring the man and parachute even when terminal velocity is reached. This is avoided if opening is delayed until the free-falling body has reached lower altitudes. The critical altitude from all tests seems to be around 25,000 feet *(7,620 metres)*. From actual incidents, serious injuries have resulted from the opening shock above 25,000 feet *(7,620 metres)*. Differences of opening shock at altitudes have

been experimentally proved. At 7,000 feet *(2,130 metres)* it was found that the average force is only 8 to 9 'G', whereas at 25,000 feet *(7,620 metres)* the average force is 19 'G' and at 40,000 feet *(12,192 metres)* 33 'G'.

(c) *Frost-bite.* This is not a serious problem if there is a free fall to at least 20,000 feet *(6,096 metres)*. On descent from high altitudes with an open parachute there is considerable danger of frost-bite.

(2) One additional danger that may occur in free fall above 45,000 feet *(13,716 metres)* is a rapid tumbling or spinning. This may be severe enough to incapacitate or seriously injure the man. If the seat is stabilized by a drogue chute the spinning may be nauseating but should not be a threat. A man free-falling on his own may control his spinning by extending his arms and legs. Whilst in free fall the man should clear his ears continually.

(3) In summary, the advantages of free fall from high altitude are:

(a) no danger of parachute fouling on the aircraft;

(b) less opening shock;

(c) less danger of frost-bite; and

(d) less danger of hypoxia due to rapid descent to safe breathing altitude.

D. Bail-Out at Low Altitude

(1) All ejection seats in current use will get a person safely out of an aircraft as low as 300 feet *(91.4 metres)* in straight and level flight; some ejection seats have a closer-to-ground capability than this. However, if the aircraft is in a dive or pulling 'G' the height requirement increases a great deal. It is essential that at low altitude the decision to eject should be made and carried out as soon as possible. If the aircraft is controllable it should be put into a climbing attitude.

(2) The automatic ejection seat overcomes the two possible dangers of free fall;

(a) inability to judge height in order to open the parachute safely; and

(b) losing consciousness and not recovering in time to open the chute.

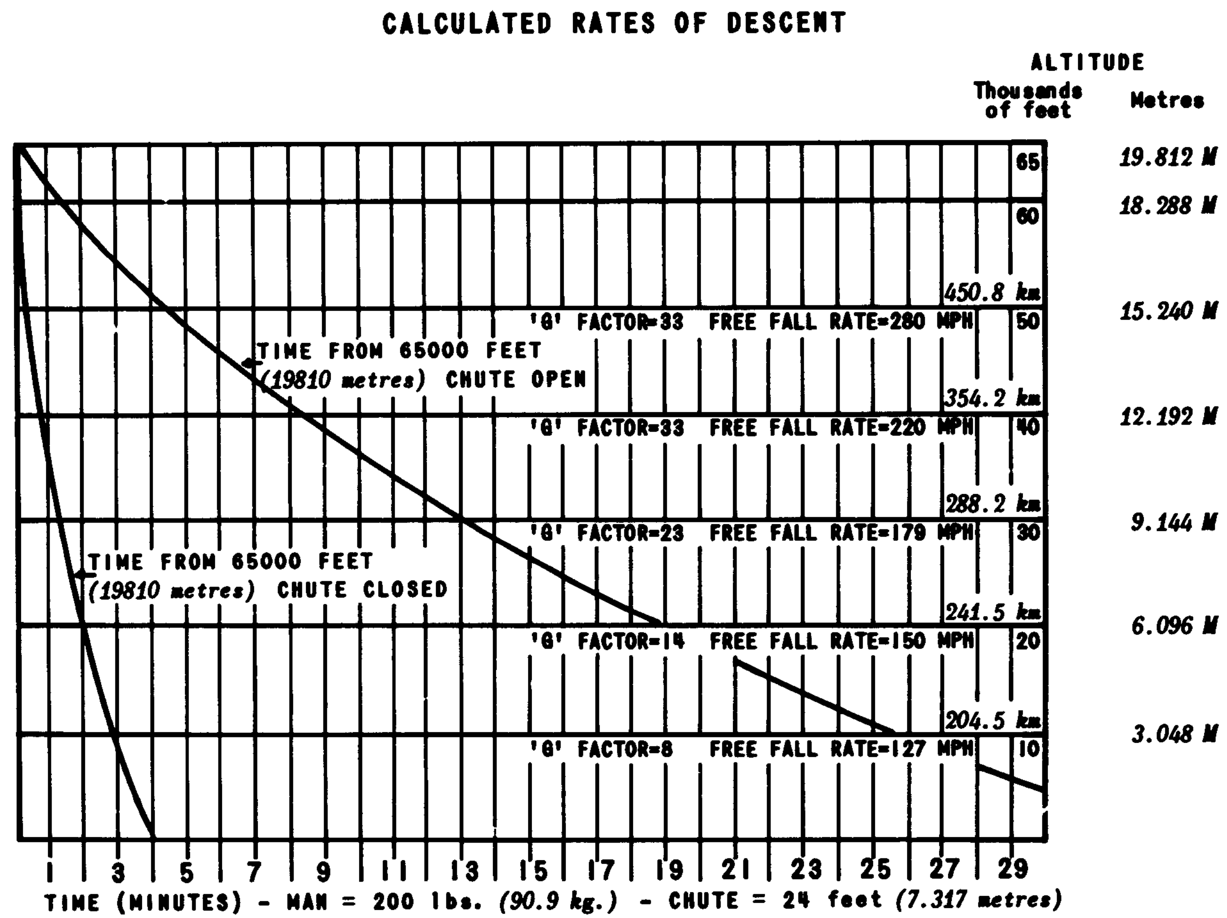


Fig. 16 Free fall and open parachute descent from 65,000 feet *(19810 metres)*

CHAPTER 9

ORIENTATION

A. General

(1) Words are interesting things. Often we use them without bothering with their exact meaning, and although they get the idea across, we lose some of the fine shades. Take 'orientation' for an example. Most people have a fair picture of what it signifies, but how many realize it is defined as 'placing oneself in relation to the east'? By usage the easterly component has been lost but the sense of direction remains. We are oriented in space when we know our position relative to the earth's surface and in time when we know the past both from the present and from the future.

(2) As we walk upon the surface of the earth, orientation is as natural to us as breathing and, most of the time, just as unconscious. When we leave the surface, going either up into the sky or down into the sea, we are faced with new difficulties in this sense and, without a knowledge of the body's orientational mechanisms, a great deal of confusion can be caused.

(3) The chief body 'instrument' for orientation is of course the eye. When we can see our surroundings, when we have a clear horizon, we are rarely confused as to our attitude. But the eye is not alone in giving us information in this way; at least five other sensing systems are at work relaying to the brain pieces of information to be correlated and combined to give the whole picture:

(a) *The Vestibular Sense Organs*. These lie in the bones of the head in close relation to the inner ear and will be discussed in detail a little later.

(b) *Muscle and Joint Sense*. You know whether a joint is flexed or straight without having to look and can easily bring your finger to your mouth in pitch black as long as this sense is operating.

(c) *Visceral Sense*. The drag on your intestine normally indicates to you which way is 'down'; you can see, however, that under 'G' loading in an aircraft this information may give rise to trouble!

(d) *Tactile Sense*. Normally you are aware of the quality of the ground under your feet or the hardness of your chair by this sense. You miss it when an arm of leg 'goes to sleep' and everyone knows how startling it is to wake up at night when this has happened and apparently have a spare limb alongside you.

(e) *Hearing*. Some information on position or on speed is derived from hearing wind or engine sounds and our hearing also places noisy objects in our surroundings by this means.

(4) An analysis by the brain of information from all these sources, salted by memory and reason, presents a picture of our position and we are oriented. Memory is invaluable, for it tells the difference in past and present time and also, under unusual circumstances, provides cues to correctly judge position from past experience. The first loop or stall turn, even in clear conditions, is confusion but the experience is filed away and is used when the same manoeuvre is repeated.

B. The Vestibular Organs and Gyroscopes

(1) The vestibular organs, one on each side of the head, are placed deep in the bones close to the middle ears. Each is approximately the size of a sixpence and consists of three semi-circular canals perpendicular to each other, each occupying one plane of space. The canals end in a common sac which is called the static organ. The whole resembles, and acts like, a gyroscope.

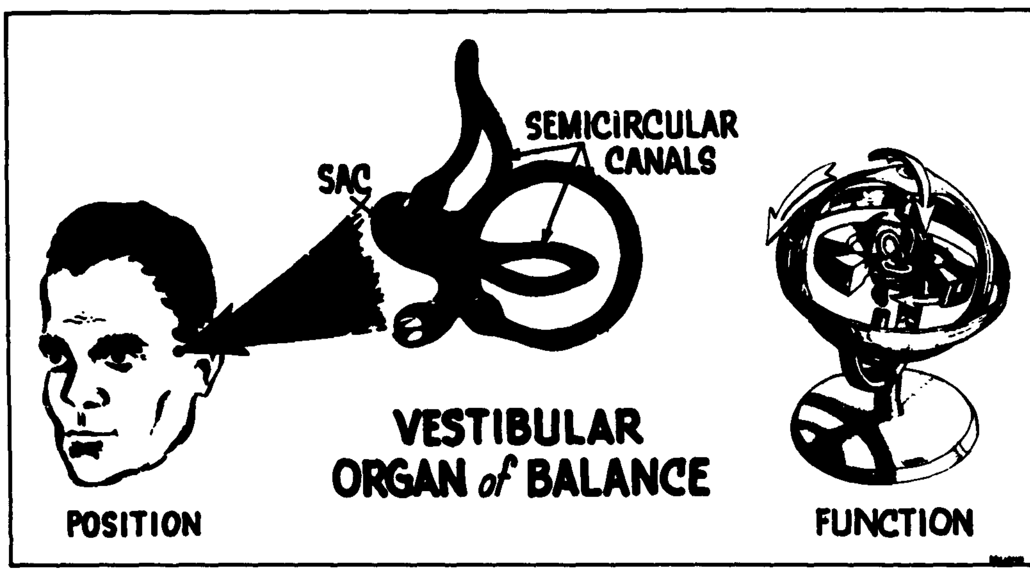


Fig. 17 The balance organ

(2) The canals and sac are filled with a viscous fluid into which project numerous fine, short hairs which are free to move back and forth when the fluid surrounding them moves. The canals are sensitive to angular movements of the head while the sac (static organ) is mainly concerned with linear acceleration. For the present we will consider the canals by themselves.

(3) When the head is moved in any direction, the canals must move with it. The fluid in the canals, however, takes a definite time to move due to inertia, so the hairs attached to the walls are deflected and the brain senses rotation. This is exactly the same as rotating a glass in which you have a drink; the glass moves *before* the drink.

(4) After this first movement, the fluid and the canals come into equilibrium if the rate of turn is constant, so the hairs are no longer deflected. The brain, therefore, is no longer stimulated and the sense of rotation disappears. Notice that the canals are only sensitive to *changes* of acceleration or rate of turn and a steady movement does not stimulate them. The best example of this is in the turning of the earth. It spins continually on its axis at a very high speed but we are not aware of it, nor shall we be unless it suddenly stops - which brings us to the next point.

(5) When the rotation of the head stops, the canals stop with it. The fluid, however, continues flowing for a fraction of time due to its inertia and the fine hairs projecting into it are bent in the opposite direction. The brain senses a turn in the opposite direction until the fluid stops.

(6) So far we have spoken of stimulating one canal at a time or of movements of the head (and body) in only one plane of space. What happens when we complicate the effect by stimulating two or more canals? This is where the analogy to a gyroscope holds most true.

(7) If a gyroscope is spinning in one plane of space and a force is applied to it in another plane at right angles to the first, it will topple (precess). The direction it moves will be in the third plane of space and the force with which it moves will be the resultant of the other two forces. So it is with the organ of balance.

(8) If we are rotating in the plane of one canal and suddenly move our heads in the plane of a second, the fluid in both canals will be set in motion. You will remember that all the canals are connected at the common sac, so the fluid in the third canal will also be set in motion and its movement will be the resultant of the first two forces. In each canal the hairs are being stimulated in different directions and the brain is being sent conflicting information. It acts by considering the largest stimulus, which will be the resultant, and therefore notifies the body that it is toppling in the third plane of space. Dizziness (vertigo) and confusion result. This reaction, which is sometimes called 'the Coriolis phenomenon', gives rise to some of the major problems in flight.

(9) 'The Coriolis phenomenon' is made use of in the mess in the game in which you place a broomstick from your chin to the ceiling and rotate about it twenty times with your eyes fixed on the tip. Dropping the broom, you then try and run through a door about ten paces away. The average man (who has not cheated) falls heavily in the middle of the floor as soon as he drops the stick, or runs rapidly into the wall!

C. The Action of the Static Organ

(1) The static organ is the common sac in which, we said, all three canals end. It is sensitive to linear motion or acceleration. It contains fine hairs projecting into the fluid exactly as in the canals and it is the movement of these hairs backwards or forwards or from side to side which stimulates the brain. The static organ acts in the same way as the ball in the turn-and-bank indicator.

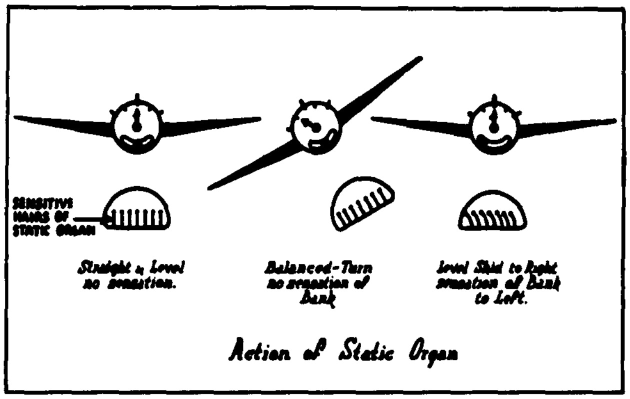


Fig.18 Action of the static organ

(2) In a well executed (ball in the centre) turn, where rudder and aileron are combined to give no slip or skid, the forces acting on the static organ will remain at right angles to the wings and you will receive no impression of tilt or bank.

(3) If, however, while holding the aircraft level, you kick on rudder and skid, the hairs will be bent to one side and you will get the sensation of a bank in that direction.

D. Thresholds of Sensation

(1) Before we can consider the problems of orientation in flight, we must discuss the thresholds of sensation to the body - the limits in fact of the body's system. We are not nearly so perceptive as we would like to think and the body can quite easily be fooled into mistakes. All of us can tell there is a difference in weight between one pound and two but how many would notice the difference between one hundred and one pounds and one hundred and two? Not very many! All our sensations work on this basic premise and it influences all we feel or do. Headlights at night are very dazzling but in daytime give only a yellow gleam. The headlight is unchanged but the contrast is gone. The body requires a contrast or appreciable movement before it senses what is going on.

(2) Experiments have shown that, without the use of the eyes, the body cannot sense a linear change of speed which exposes it to less than 1/50 'G'. This may seem small but your forward speed can change in this way by 20 knots a minute without its being brought to your attention.

(3) In the same way there is a threshold below which rotation or change in attitude is not sensed. If you are rotated at a rate slower than one degree per second per second, no organ in your body will indicate to you that you are rolling, as long as you cannot see and the 'G' force does not change. You could actually turn completely over on your back in the air without being aware of it and this has happened many times. This threshold is the one which allows you to 'drop a wing' in cloud without noticing it.

(4) Any carpenter will know that we cannot accurately judge what is level; here again the body has its limits. In the plane of pitch in an aircraft, it is possible to get 10 degrees nose-up or 20 degrees nose-down without noticing if the movement is slow and the pilot unable to see.

(5) One final limit to remember is that the body only senses changes of movement of acceleration. This came up before when we were discussing the vestibular organ. The result of this is that, once you have entered a turn and set up a steady speed of rotation, all the sensation of turning disappears until you *change* the speed.

E. Disorientation and the Flyer

(1) So far we have talked of orientation entirely and have discussed the body's mechanisms for achieving and maintaining it and the body's thresholds to positional changes. Now we must look at the other side of the coin - disorientation.

(2) Disorientation is literally 'difficulty (dys = difficulty in Greek) in facing ourselves to the East' or, by usage, 'difficulty in appreciating our position relative to the earth and our surroundings'. You may be disoriented in space, in time, or in both. When you wake up after a party not knowing where you are or what day it is, you have the picture.

(3) Disorientation is one of the commonest problems of the flyer and as such it is a situation you must understand and appreciate if you are to cope with it. Make no mistake, disorientation in some form will affect you in your flying career but it is *NOT* a disease or something to be afraid of. It must simply be understood.

(4) You may become disorientated by failure of any or all of the body's sensing mechanisms to give you correct information. We can usefully divide disorientation into two main categories. In the first our body fails to sense what is going on and in the second it misinterprets what it is sensing. An example of the first is 'the leans' (see Figure 19), and of the second, the sensation you get whilst sitting in a stationary railway car when the train beside yours starts to pull away. You feel yourself going backwards.

(5) An exaggerated example of the latter type was the man driving along in his car at 60 m.p.h. who, on being suddenly passed at very high speed by a sports model, stepped out to see why he had stopped!

(6) The 'leans' are the commonest form of disorientation which the flyer experiences and are simply a result of the thresholds of sensitivity we discussed. You are flying along in cloud, paying little attention to your instruments, when you happen to notice from the attitude gyro that one wing is low. It has fallen so slowly that you did not sense the change. Quickly you pick up the wing with aileron and this movement is made rapidly enough to be sensed. Since the body did not know there was any tilt to be corrected and the brain only sensed the recovery, it is left with the unfortunate impression that the aircraft is tilted towards the side to which recovery was made. You are now suffering from the 'leans', so-called because the conviction of tilt is so strong that you will subconsciously lean towards the other side of the aircraft to try to balance the feeling!

Fig.19 The 'leans'

(7) Instruments are put into aircraft so that we will know our position at all times regardless of outside visibility. Properly used they will give you all the information required for orientation at all times. To do this, however, instrument cross-check must be rapid, complete, and continual; looking in and out of the cockpit in cloud or haze is asking for trouble. Many a pilot has gone visual too early before breaking out of cloud and has found to his surprise on breaking out that he is in a steep bank or even inverted. Knowledge is the keystone, and instruments should have become such second nature that the information they give you is complete and satisfying to all your sensations. This is the result of training and is called conditioning.

(8) Events falsely sensed or misinterpreted are a cause, time and again, of aircraft incidents. Making a spin recovery on instruments, opposite rudder is used until the rotation ceases and then the controls are centralized. When the rotation ceases, however, the fluid in the semi-circular canals continues to flow for a moment and you will remember that a sensation of turning in the opposite direction occurs. This sensation has often led pilots to believe they have entered a spin in the opposite direction and, using hard rudder again, they re-enter the spin. This chain of events is known as the 'graveyard spin'!

(9) Another frequent cause of disorientation is the 'Coriolis phenomenon'. Whilst making a sharp pull-up or turn, the pilot rotates his head swiftly in look-out or for position. Two canals have been stimulated and a tumbling sensation comes on accompanied often by nausea and confusion. Beware of sudden head movements!

(10) An experienced pilot knows this and uses his eyes to save his neck. Eye movements do not stimulate the balance organ in the same way and so do not lead to disorientation. Any head movements which you need should be slow and smooth; hurry and jerkiness make for bad flying. Experience is something that requires time but you can gain some experience on the ground which will help you to appreciate the problem more fully. It is strongly recommended that you become familiar with vertigo (dizziness) by the following safe, simple procedure.

F. A Demonstration of Disorientation

(1) First, have someone rotate you on a piano stool. You will notice that, with your eyes closed and your head upright, there is little sensation of turning if a constant speed is reached. If the stool is suddenly stopped, however, you will find that you experience an immediate feeling of rotation in the opposite direction. If you have been spinning rapidly or for a long period you may even feel dizzy.

(2) Now, while spinning on the stool, turn your head rapidly upwards or downwards; the result will be that you will feel everything tilt sharply and will have great difficulty in maintaining your balance. If the rapid head movement is sideways, you will fall forward or backward depending upon the side to which you turn. It is wise to have someone to catch you in case you fall.

(3) If you look at a man's eyes while he is experiencing vertigo, and have him fix them upon one spot, you will see that they are moving slowly away and then flicking rapidly back to the spot. This is called nystagmus and the slow movements follow the plane of the canal in which the greatest movement of fluid has taken place.

(4) It is well worth your while to have experienced vertigo and to have watched its effects on other people. If you superimpose your head movements slowly on the rotation, you will find it does not occur. Remember that these are normal reactions which can occur to anybody - they are not signs of an illness! Vertigo (dizziness) has its *good points* although it may produce nausea or discomfort. It is an indication that we are becoming, or have become, disoriented and so we can take action. This is better than having disorientation sneaking up on you unaware.

G. Cases in Point

(1) When disorientation occurs in the air, it can have very serious consequences but, with knowledge, all this can be dealt with or avoided. Before going on to discuss its prevention and treatment, here are a few cases when it really happened.

(2) A light transport aircraft was on a night navigation training flight. The sky was clear. There was no moon, but the stars were quite bright. Snow covered the ground and the area was uninhabited with no lights anywhere. The pilot did a 270-degree turn (30 degrees of bank) and after quickly levelling out he glanced through the side window. The whole sky immediately seemed to rotate and the stars appeared briefly below. He went back on to instruments, which indicated straight and level flight, and stayed on them until the sensation disappeared.

(3) A T-33 aircraft was on a night flight at 38,000 feet *(11,582 metres)*. The sky was clear with bright stars and northern lights. After the trip the pilot let-down in

a turn to 24,000 feet *(7,315 metres)*. During the turn he moved his head to look away from the instruments. Immediately he experienced a violent sensation of vertigo, the sky rotating about him so that the stars appeared to him to be underneath the aircraft. He temporarily lost all control in the resulting confusion and could only right himself by holding the control column with both hands and concentrating his attention on the instruments. The co-pilot in the back seat underwent similar sensations which he was able to overcome by flying under the hood. Both pilot and co-pilot were visibly shaken by the experience and later credited their survival to concentration on the instruments.

(4) It should be emphasized that vertigo can happen to any normal person and that all aircrews can expect to experience it some time. Try to understand why it occurs and respect its existence as a dramatic warning which you can successfully heed by quickly focusing your eyes *intently* on the instruments.

(5) During straight and level flight, a sudden change in flying speed without any turning of the aircraft will produce on the pilot a resultant force which is no longer directed downwards. This accounts for the illusions of nose-down attitude reported by pilots as having occurred when the dive brakes were suddenly applied. A sudden boost in power will evoke the sensation of a nose-up attitude for the same reasons. This may occur with rocket-assisted take-off.

(6) One may well ask, 'How is it that a pilot, even when he is not exposed to these accelerations, can allow his aircraft to get into a position of which he is unaware?'. One answer lies in the threshold of an individual's sensitivity. Individuals differ in the degree to which they react to acceleration but, as mentioned earlier, we are not nearly so perceptive as we should like to believe. A slowly dropping wing in cloud is *not* apparent unless you are concentrating on a rapid and complete cross-check of your instruments. On long trips and 'bird-dogging' we tend to become careless.

(7) A good example of the 'Coriolis phenomenon' and its effect in flight comes from a report of a Canadian pilot with 500 jet hours. '... take-off was made at night in heavy snow and a ceiling of 600 feet *(182.9 metres)* and visibility 1 mile *(1.61 km)*. On take-off, radio contact with the tower was lost and while a slow climbing turn to the left was commenced, I attempted to switch on the radio compass audio to see if my clearance was being given over the radio compass. The switch is on the right console rather far back. Not finding it by touch, I turned my head quickly downwards and to the right to locate it. As I did so, the aircraft appeared to be struck a heavy blow on the left wing and everything started to go round. I swung back and checked the artifical horizon but thought it must have toppled as it was going round and round. I tried to locate the IAS on the left of the panel but couldn't find it because the whole panel seemed to be rotating violently. I felt very dizzy and had no idea of where I was.'

(8) The pilot recovered control of the aircraft after several violent manoeuvres, including an inverted climb at 4 negative 'G' followed by two stalls. (The artificial horizon had not toppled but was correctly recording a continuous roll to the right!) While attempting to recover from inverted flight he found '........... the stick got very heavy although I was not near the limiting Mach. My instruments said that I was in a 60-degree bank to the left but I had difficulty in believing them. The stick was over to the left and seemed to be trying to move further across. With both hands

and my left knee I could just move it and felt that if I let go it would smash across onto my left leg. The hydraulic pressure was normal but, not noticing this at first, I nearly deboosted the controls.'

(9) The pilot finally relaxed his death-like grip on the stick and immediately the heavy stick pressures disappeared. What he had been fighting was his mind which believed that he was straight and level and that movement of the stick to the right would worsen his condition. Many people have reported that stick forces become heavy during disorientation and that it feels 'as if a giant hand were pushing the stick away'. This example of the 'Coriolis phenomenon' is similar to the man sitting on the rotating piano stool and suddenly moving his head in the opposite direction and downwards; the difference is that in an aircraft the fall is farther!

(10) Vision can lead to disorientation without any other disturbance in the organs of balance. Flying at night, when the horizon is obscure and the northern lights are slanted, frequently produces difficulty. Often, at high altitude, lights on the ground and the stars seem to become interchangeable and it is very difficult to know which way is up. The moon, low on the horizon, develops the illusion that you are above it and this makes it seem as though the sky is below. The effect is heightened by the ground lights, resemblance to stars.

(11) A classical case is reported of a senior pilot flying a Canso between layers of cloud who was passed by three Sabres in formation, all of which were inverted. It is said that the confused pilot of the flying boat spent the next ten minutes trying to get it upside down!

(12) Another optical illusion took place while a Canadian pilot was flying at night on top of a cloud layer with starlight above. As he reached a new cloud formation extending vertically, he found himself dropping one wing through 90 degrees in order to line up with the cloud formation which was at right angles to the previous one. This disorientation effect was enhanced by the appearance of ground lights from below. These blended with the stars so that the effect was one of continuous sky above the pilot's head and continuous cloud below, even though the aircraft was flying 90 degrees off the true horizontal.

H. How to Live With Disorientation

(1) It now remains to try and put this condition in its correct perspective. Disorientation is a large problem, no doubt of that. But so is flying an aircraft. It is not a situation to be afraid of as long as it is understood, nor is it any more difficult to prepare for than any other in-flight emergency.

(2) We have discussed the ways it occurs and to some extent when it occurs. Let us briefly summarize these:

(a) *Conditions under which disorientation is frequent*

(i) entering or leaving cloud,

(ii) in cloud or between layers,

(iii) at night and in haze,

(iv) during aerobatics or violent manoeuvres, and

(v) on turns in formation; and

(b) *Factors leading to disorientation*

(i) rapid, jerky head movements,

(ii) inattention to instrument cross-check,

(iii) transition from instrument to VFR too early,

(iv) fatigue and anxiety, and

(v) inexperience.

(3) With these points in mind, the majority of cases can be avoided. Flying in IFR conditions your full attention should be upon your instruments and glancing out of the cockpit is not the answer. You must go to your instruments early rather than late; as you penetrate cloud and lose sight of the horizon you should be on the dials, not just thinking of going onto them.

(4) Experience is a great teacher and, when you are suffering from vertigo, you need everything working for you. Whilst a student, unusual positions under the hood are stressed, but too often the unit pilot doesn't bother to keep up the practice. Being disoriented in cloud is quite a different picture from disorientation experienced when you have visual reference.

(5) The best advice to all is *rely upon your instruments*. If all of these have let you down you shouldn't be still aboard!

CHAPTER 10

DECOMPRESSION SICKNESS OR BENDS

A. Mechanism

(1) It is common knowledge that fish breathe through their gills by absorbing oxygen dissolved in the water. Nitrogen as well as oxygen is dissolved in water under the pressure of the atmosphere. This applies equally to the human body, nitrogen and oxygen being dissolved in the fluids of the blood and tissues, although nitrogen, being less soluble than oxygen, is dissolved in relatively small amounts.

(2) With increasing altitude the pressure holding the nitrogen in solution in the blood and tissues is reduced. Part of it comes out of solution and minute bubbles are formed, since nitrogen cannot be excreted quickly enough by the lungs.

(3) This principle may be demonstrated by removing the cap from a bottle of any carbonated beverage. The gas, which is dissolved under pressure during manufacture, comes out of solution and forms bubbles.

B. Symptoms

(1) The small bubbles of nitrogen that form in the blood and tissues of the human body at the reduced pressure of the higher altitudes cause a variety of symptoms, the most common being the following:

(a) *'Cramps' (the bends)*. Bubbles forming in muscles and joints may cause cramp-like pains. The 'cramps' are aggravated by exercising the affected joints or massaging the affected muscles. The limbs are more usually affected, especially shoulder, ankle, wrist and knee joints. 'Cramps' may also appear frequently at the location of old injuries, e.g. fractures.

(b) *'Creeps'*. An itching, creeping, or crawling sensation in the skin, or a localized feeling of heat or cold, all due to bubbles forming in the skin.

(c) *'Chokes'*. There is a difficulty in breathing, a tendency to cough, a sensation of choking, or a burning in the chest, probably due to the formation of nitrogen bubbles in the tissues of the lungs.

(d) *'Collapse'*. This usually follows prolonged and severe suffering from any of the above symptoms, but has been known to occur without any previous warning. It can be prevented by heeding the 'early warnings' discussed above.

(2) Bends seldom occur below 30,000 feet *(9,144 metres)* and even at 35,000 feet *(10,668 metres)* a fairly long exposure is needed to produce symptoms. In fighter aircraft, because of their short endurance and pressurized cabins, the condition is rare.

However, in the event of total or partial loss of cabin pressurization where flight must be continued at high altitude, severe bends could occur within a short period in some individuals. Bends also occur in decompression-chamber training.

C. Incidence

Probably all people are liable to bends if at high altitudes for long periods of time. People under the age of 30 will rarely encounter this condition below 25,000 feet *(7,620 metres)*.

D. Factors Affecting Appearance of Bends

The appearance of bends is influenced by:

(a) *ultimate altitude reached* – the higher, the more likely the bends;

(b) *rate of climb* – the faster, the more likely the bends;

(c) *time at altitude* – the longer, the more likely the bends;

(d) *physical exertion* – at altitude, tends to accelerate onset;

(e) *body build* – overweight people are probably more susceptible to bends than thin people;

(f) *cold* – predisposes to onset of bends; and

(g) *altitude at which the individual normally resides* – people who live at high altitudes are less susceptible.

E. Factors NOT Affecting Production of Bends

The production of bends is not related to the type or amount of food eaten or to fatigue.

F. Prevention of Bends

(1) The use of pressure cabins or pressure suits prevents the formation of nitrogen bubbles, since the pressure is high enough to keep nitrogen dissolved in the body fluids.

(2) Removal of nitrogen from the body before flight can be accomplished by breathing a nitrogen-free gas mixture. This is known as nitrogen desaturation and can best be achieved by breathing 100 per cent oxygen for 40 to 50 minutes. Similarly, use of 100 per cent oxygen from ground up, if ascending to a high cabin altitude, will hasten nitrogen desaturation.

G. Treatment of Bends

Immediate descent, which increases the atmospheric pressure, usually relieves the symptoms of decompression sickness rapidly. Once developed, bends will not pass off

unless corrective action is taken. It is dangerous to try to continue a high altitude flight with even mild 'bends'. The condition is very unpredictable and can quite suddenly produce severe collapse.

CHAPTER 11

EFFECTS OF FLIGHT ON THE EARS, SINUSES, AND ABDOMINAL GAS

A. The Ears - Anatomy

(1) The ear (Fig.20) consists of three parts: the external ear, the middle ear, and the internal ear. The middle ear consists of a small cavity in one of the bones of the skull. Two tubes or canals lead from this cavity; one, the external auditory canal, to the opening in the external ear, and the other, the Eustachian tube, to the back of the throat and nose.

(2) The external auditory canal is an inch-long cylindrical tube, and across its inner end is stretched a thin airtight membrane called the ear-drum. Sound vibrates the ear-drum, the vibrations being transmitted through the middle ear by the tiny bones (the ossicles) to the inner ear where the cochlea converts the vibrations to nerve impulses which are perceived by the brain. The Eustachian tube is narrow and lies in a bone canal for most of its length. Its end opening into the throat tends to act as a flap valve permitting air inside the middle ear to escape to the nose and throat easily but tending to resist re-entry of air from nose and throat, unless aided by muscular action in the throat.

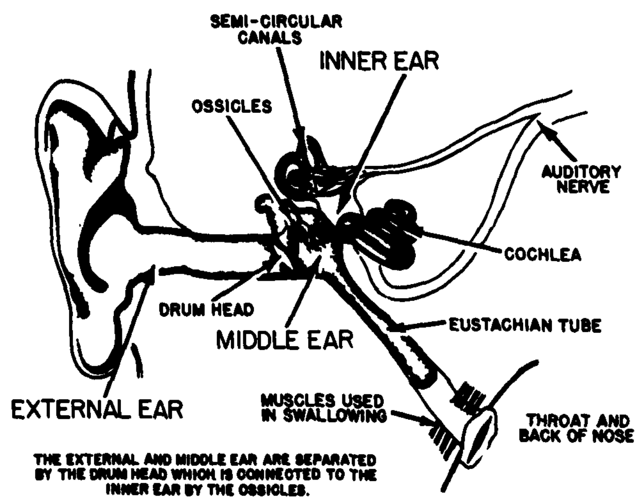


Fig.20 The ear in cross-section

B. Effects of Ascent and Descent

(1) During ascent, the air pressure in the middle ear cavity decreases slower than the pressure in the air outside. This bulges the drum outwards, causing a feeling of fullness in the ear. These pressures are equalized, however, by air passing down the Eustachian tube from the middle ear cavity into the throat. You may feel or hear a

sudden click when the Eustachian tube opens, and notice an immediate relief from the feeling of fullness. Damage to the normal ear-drum rarely occurs during ascent, since the air can escape easily through the Eustachian tube.

(2) During descent, the air pressure becomes less in the middle ear than outside, so, to equalize the pressures, air must enter the middle ear cavity from the throat through the Eustachian tube. The equalization occurs with difficulty, owing to the tendency of the Eustachian tube to act as a one-way valve. Normally the entrance to the Eustachian tube is opened by the contraction of muscles in the throat, such as occurs when you swallow or yawn. If this pressure differential is not relieved, it causes temporary deafness and pain.

(3) Following a flight to high altitude in which 100 per cent oxygen has been used, an aircrew member may sometimes experience these symptoms many hours later and particularly on the following morning. This is caused by the absorption of oxygen into the mucous membranes of the middle ear, producing a pressure differential across the ear-drum. These symptoms may be alleviated by performing several Valsalva manoeuvres (explained below) after the flight and before retiring to bed that night.

C. 'Clearing' the Ears on Descent

If the pressure difference is not equalized by the passage of air from the throat to the middle ear cavity, the drum may continue to bulge inwards until it perforates. If the airman fails, when descending, to keep the Eustachian tube open by repeated swallowing, the pressure build-up may be so great that swallowing will no longer clear the ears. If this occurs, air from the throat can be forced through the tube by holding the nose and mouth closed while trying to blow the nose at the same time. (This greatly increases the air pressure in the throat and is called the Valsalva manoeuvre.) Should this be ineffective it will be necessary to level-off or ascend until the ears can be cleared. Other methods of clearing the ears on descent are yawning, forward movement of the jaw, or shouting.

D. Factors Affecting Ability to 'Clear' Ears

(1) Colds and catarrh cause a swelling and partial blockage of the Eustachian tube and difficulty in clearing the ears may result. Do not fly with a cold. This precaution may prevent a perforated ear-drum and, although it generally heals rapidly, there may be impairment of hearing and prolonged disability from infection of the middle ear. If the ears cannot be cleared in flight, reporting to the flight surgeon immediately may save weeks of trouble.

(2) Repeated practice in clearing the ears will increase the rate of descent which can be borne without discomfort.

(3) During sleep, the Eustachian tube is not unconsciously opened in descent, and captains of aircraft should ensure, therefore, that passengers are awakened before descent is started.

(4) When descending rapidly at low altitudes, extra care must be taken to clear the ears because greater atmospheric pressure changes occur for any given height change at low altitude as compared to high altitude. For example, the change in atmospheric

pressure between 10,000 feet *(3,048 metres)* and 5,000 feet *(1,524 metres)* is almost double that between 30,000 feet *(9,144 metres)* and 25,000 feet *(7,620 metres)*.

E. The Sinuses - Anatomy

The nasal sinuses are air-filled cavities located in the bones of the forehead and cheeks and connected with the nose by small openings. The mastoid air spaces in the bone just behind and below the ear are similarly connected to the middle ear cavity.

F. Effects of Ascent and Descent

The openings of these sinuses into the nose are small and have a lining of mucous membrane. If this mucous membrane swells, as in a cold, the openings are closed, since the bone surrounding the opening forces the swollen mucous membrane towards the centre. When the openings are closed, the air pressure in the sinuses may be quite different from that outside, just as occurs in the middle ear. This may cause severe pain, either on ascent or descent, and the remedy is to return to a lower altitude if ascending or to a higher altitude if descending, than that at which the pain occurred. Often a slower descent will permit the sinuses to ventilate, particularly if aided by gentle Valsalva manoeuvres. If pain persists to ground level, consult the Flight Surgeon immediately.

G. Expansion of Gas in the Abdomen

(1) Most of the gas in the intestines is swallowed air. In the course of digesting food, however, a certain amount of gas is generated in the intestines and normally expelled. The amount of gas present varies with the individual and with the type of food eaten, e.g. beans and cabbage are highly gas producing. This gas expands with the decrease in atmospheric pressure at altitudes and, if not expelled, stretches the walls of the intestines causing symptoms ranging from discomfort to severe abdominal pain.

(2) In slow ascent there is usually time to expel these gases by rectum, but with a rapid rate of ascent, gas is more likely to be trapped and cause discomfort. This is especially noticeable in rapid decompressions. Every effort should be made to get rid of intestinal gases during ascent.

(3) If high-altitude flying is expected, the following 'Diet Don'ts' may help to minimize abdominal gas:

(a) don't eat too quickly;

(b) don't eat too much;

(c) don't drink gassy beverages (e.g. carbonated beverages, beer, milk shakes); and

(d) don't eat gas-forming foods (e.g. beans, cabbage, greasy foods).

CHAPTER 12

RAPID DECOMPRESSION

A. General

If, when flying a pressurized aircraft at high altitude, the cabin is punctured or the canopy releases, the effect on the flyer will be that of an extremely rapid ascent as the pressure in the cabin escapes. The pressure in the cabin will fall through the total pressure differential in use at the time. This might be equivalent to a sudden altitude change of several thousand feet *(metres)*. Such an occurrence is known as 'rapid decompression'.

B. Immediate Effects

(1) With the pressure differentials normally used, rapid decompression is unpleasant but not immediately dangerous. The chief immediate effects on the human body are the following:

- (a) Fright due to the explosive noise. For an instant the flyer may think that the whole aircraft has exploded.
- (b) Cooling due to rapid expansion of air. If the cockpit is protected from slipstream blast and the relative humidity is high, a fog may appear as the water vapour in the air suddenly condenses; the flyer may think this is smoke. Fog may be dense enough to interfere momentarily with reading of instruments and may be interpreted as sudden blindness.
- (c) Sudden expansion of air in the lungs and a violent exhalation through the nose and mouth, making the cheeks flutter and the oxygen mask jump from the face momentarily.
- (d) Slight deafness and ringing in the ears which clears immediately.

(2) Frequent repeated rapid decompressions, or a single decompression when the pressure change is abnormally large and rapid, could result in damage to the lungs.

C. Severity of Effects

(1) The violence of a rapid decompression and its effect on the body depend on the rapidity of the decompression, which in turn depends upon:

- (a) the pressure differential and the altitude, (i.e. the ratio of cockpit pressure to ambient pressure);
- (b) the volume of the cabin; and
- (c) the size of the hole or leak.

(2) The safe limit for the rate of decompression of the human lung is not exactly known but is far more rapid than could conceivably occur in present-day pressure cabins, short of a total cabin disintegration.

(3) Fighter aircraft with their small cockpits are not pressurized beyond 5 pounds per square inch (many only to 2.75 psi). However, large cabin aircraft, such as bombers and transports, may be pressurized up to 8 pounds per square inch differential. This gives a cabin pressure altitude of 8,000 feet *(2,438 metres)* when flying at approximately 39,000 feet *(11,887 metres)*. Higher pressurization is not necessary or economical.

(4) In large pressurized aircraft there is danger of ejecting occupants through a blown-out window, door or hatch. This occurred in a civilian aircraft when a door blew open under pressure, carrying an unsecured passenger out in the escaping air, and navigators have been blown through shattered astrodomes. Safety harnesses should be used in crew positions in the vicinity of potential openings in pressurized aircraft.

D. Consequences of Rapid Decompression

Having weathered the immediate effects of a rapid decompression, the loss of the protection of the cabin pressure presents problems. These are different in fighter and transport aircraft.

(a) *Fighter*. The rate of change of pressure is much higher and therefore, the effect more startling. While harmless, in the confusion the delay in corrective action may be dangerous. The most serious effects are as follows:

(i) *Hypoxia*. This is prevented by the automatic delivery of pressure breathing. The sudden onset of pressure breathing is disconcerting. The mask should be tightened to hold the pressure and descent should be initiated.

(ii) *Cold*. Ambient air at altitude is very cold.

(iii) *Blast*. The slipstream blast, if the canopy is lost, affects vision and hearing.

(iv) *Abdominal Gas*. The sudden expansion of abdominal gas can be painful. Do not pull the ejection seat in the moment of panic; despite some evidence to the contrary the aircraft has not blown up (only your bowels). A rapid and controlled descent relieves the situation.

(b) *Transport*. The decompression is less rapid and dramatic. The pilot should be using oxygen at all times as a precaution. The crew should have masks at readiness. It is essential for the rest of the crew to get the masks on as rapidly as possible, because the times of useful consciousness are disastrously short above 30,000 feet *(9,144 metres)*. The pilot must initiate a descent to at least 14,000 feet *(4,267 metres)* as rapidly as possible, if he is carrying passengers. Even in those

passenger aircraft in which there is an automatic presentation of masks to the passengers following pressure loss, the passengers cannot be relied upon to use them properly under emergency conditions.

CHAPTER 13

EFFECTS OF HEAT AND COLD

A. Temperature of the Atmosphere

From the ground level to 35,000 feet *(10,668 metres)*, the temperature decreases approximately 3.5°F. *(2°C.)* per 1,000 feet *(304.8 metres)* and above 35,000 feet *(10,668 metres)* remains constant at about -67°F. *(-55°C.)*. Variations occur, but these figures are approximate.

B. Temperature Control of the Body

(1) The body temperature in health is automatically controlled at an average of 37°C, the main controlling mechanism being the skin.

(2) When the body temperature drops, the flow of blood through the blood vessels of the skin is reduced by nervous control and the skin becomes cold, decreasing loss of body heat to the surrounding air. This effect can be likened to that of turning down a steam radiator. The body also attempts to generate more heat by causing small rhythmic contractions of the body muscles, i.e. shivering.

(3) When the body temperature rises, the flow of blood through the skin is increased and the skin flushes and becomes warm, increasing loss of body heat to the surrounding air. If still more heat loss is required, the skin starts to sweat and the evaporation of the sweat removes large amounts of heat from the body.

C. Effects of Cold on Aircrew

(1) Body chilling reduces efficiency and causes discomfort.

(2) Local chilling, if severe, causes frost-bite or freezing of the tissues.

D. Factors which Increase Susceptibility to Cold

Factors increasing susceptibility to cold are as follows:

(a) *Inadequate Clothing.* Regardless of the temperature on the ground, adequate clothing should be worn on high-altitude trips, to minimize the effects of cabin heat breakdown or bail-out at very low temperatures. Several layers of thin material are better than one layer of thick material because of the increased insulating air space between layers. Clothing should be loose-fitting, especially gloves and boots. Aircrews can, with practice, get used to carrying out jobs, requiring sensitive touch, wearing thick gloves.

(b) *Insulation Qualities of Moist Clothing.* Moisture decreases the insulation value of clothing, and all flying clothing should, therefore, be dry before flight. Flying boots should be put on just before flight, otherwise they become damp from sweat.

(c) *Alcohol and Its After-Effects.* Alcohol disrupts the normal temperature control mechanism of the body.

(d) *Hypoxia.* Reduces heat production.

(e) *Lack of Activity.* This is especially present in fighter aircraft.

E. Frost-bite

(1) Local freezing of the tissue may produce a tingling in the area, or may be unnoticed, but, as the tissue freezes, it becomes numb, white and hard.

(2) Treat by warming at body temperature. Hands may be warmed by putting them next to the skin under the armpits; feet by placing them next to another person's skin or in water at a temperature of 100–110°F. *(37.8–43.3°C.).*

(3) Frost-bitten areas should NEVER be rubbed with snow and NEVER placed close to a fire or in hot water.

F. Effects of Heat on Aircrew

(1) Aircrews may be exposed to extreme heat while sitting at readiness on a hot summer day or at altitude, due to direct sunlight.

(2) Excessive sweating for long periods may deplete the salt content of the body and lead to heat cramps and heat exhaustion. Milder degrees of salt loss cause muscular weakness.

(3) Extreme heat may cause prostration.

G. Factors that Increase Susceptibility to Heat

Heat susceptibility may be increased by:

(a) *impermeable constricting clothing* which reduces the amount the body may lose by evaporation of sweat;

(b) *lack of salt in the diet,* especially in the summer when sweating is profuse – extra salt should be taken with meals or in the form of salt tablets; and

(c) *alcohol and its after-effects* – alcohol disrupts the normal temperature control mechanism of the body.

CHAPTER 14

NOISE

A. Characteristics of Sound

(1) Any unwanted sound is noise. Aircrews and groundcrews, by the very nature of their jobs, will be exposed to noise. Therefore, a knowledge and understanding of noise and noise protection is essential to the promotion of safety and efficiency in flying operations. As you know, there is a variety of kinds of noises and sounds. The characteristics of sound should be understood prior to any discussion of the problems of noise.

(2) Sound, being wave motion, possesses three basic characteristics which concern us:

(a) frequency;

(b) intensity or loudness; and

(c) quality or timbre.

(3) The frequency of a sound is measured in terms of the waves per second, which are commonly referred to as cycles per second (cps). The frequency of a sound governs whether we hear this sound as a high note or a low note. The human ear is capable of hearing sounds of frequencies from 20 cps to approximately 20,000 cps; the upper limit of this hearing capability tends to decrease with age. For the sake of reference, Middle C on a muscial instrument has a basic frequency of 256 cps and the audio tone of a Low-Frequency Radio Range Station has a frequency of approximately 1,000 cps. Principal speech frequencies occupy the approximate range of 300 to 6,000 cps.

(4) Intensity or loudness is a measure of how much energy is put into creating a sound. The greater the intensity of the sound, the more energy there is in the sound. The ear judges sound not only by frequency but also by intensity. Two sounds of equal intensity and frequency will sound equally loud; however, two sounds of the same intensity but of different frequencies may be observed as being of *different* loudness. The unit of measurement of sound intensity is the decibel (db). The decibel is a measurement of the amount of energy in a sound (sound pressure level (spl)) in relation to a basic sound pressure level. The decibel is derived from a mathematical equation and this equation is such that for every increase of 6 db the actual energy in the sound is doubled. Hence, if you have two sounds of 100 db sound pressure level, the spl of the combined sound would only be 106 db. The energy in sounds compared to the spl may be seen in Table I. Jet-engine noise is most intense in the speech frequencies, whereas piston-engine noise is concentrated at lower frequencies.

Note for the Mathematically Inclined

$$\text{Sound Pressure Level (spl) in decibels (db)} = 20 \log_{10}\left(\frac{\text{Pressure A}}{\text{Pressure B}}\right)$$

where Pressure A = sound being measured (dynes/cm^2)
Pressure B = standard (0.0002 dynes/cm^2).

(5) Quality or timbre of sound is that property by which we detect the difference between two sounds, e.g. Middle C played on a violin and a saxophone. We know that one note comes from a violin, the other from the saxophone, although the note played by each has the same basic frequency. This characteristic of differentiation is quality and is caused by a number of variable factors which make the instruments different.

B. Effects of Noise

(1) Exposure to noises of high intensity may cause:

(a) a change in hearing acuity;

(b) a change in voice communication efficiency;

(c) damage to the body other than the hearing mechanism;

(d) changes in overall efficiency; and

(e) feelings of fear, apprehension, annoyance and dissatisfaction.

(2) You probably have experienced one or all of the above effects to a mild degree at some time. For instance, you may have experienced the 'feeling' of an explosion of a large gun, the temporary loss of hearing following exposure to engine noise during 'run-up', the difficulty in working when a pneumatic drill is operating outside your window, or annoyance at the screaming of a child.

(3) Long-time exposure to loud noise may cause temporary or permanent deafness. However, the use of proper ear protection equipment should prevent permanent deafness if the noise level does not exceed 150 db.

(4) Ear pain, which will occur at approximately 130 db for most people, is not a good indicator of whether noise is harmful or not. Ear pain will occur at noise levels approximately 35 to 45 db higher than the levels required to damage the hearing mechanism by years of exposure to noise.

(5) Fortunately, overall noise levels in aircraft seldom exceed 120 db; however, continuous exposure to these levels can be damaging. For this reason, hearing protection criteria for long-time exposure to noise have been produced. (See Table II). It is to your advantage to adhere to the protection standards for this Table. (See also section C: Protection from Noise)

(6) Voice communications will obviously be affected in areas of high noise level. However, voice communication under these conditions can be improved by:

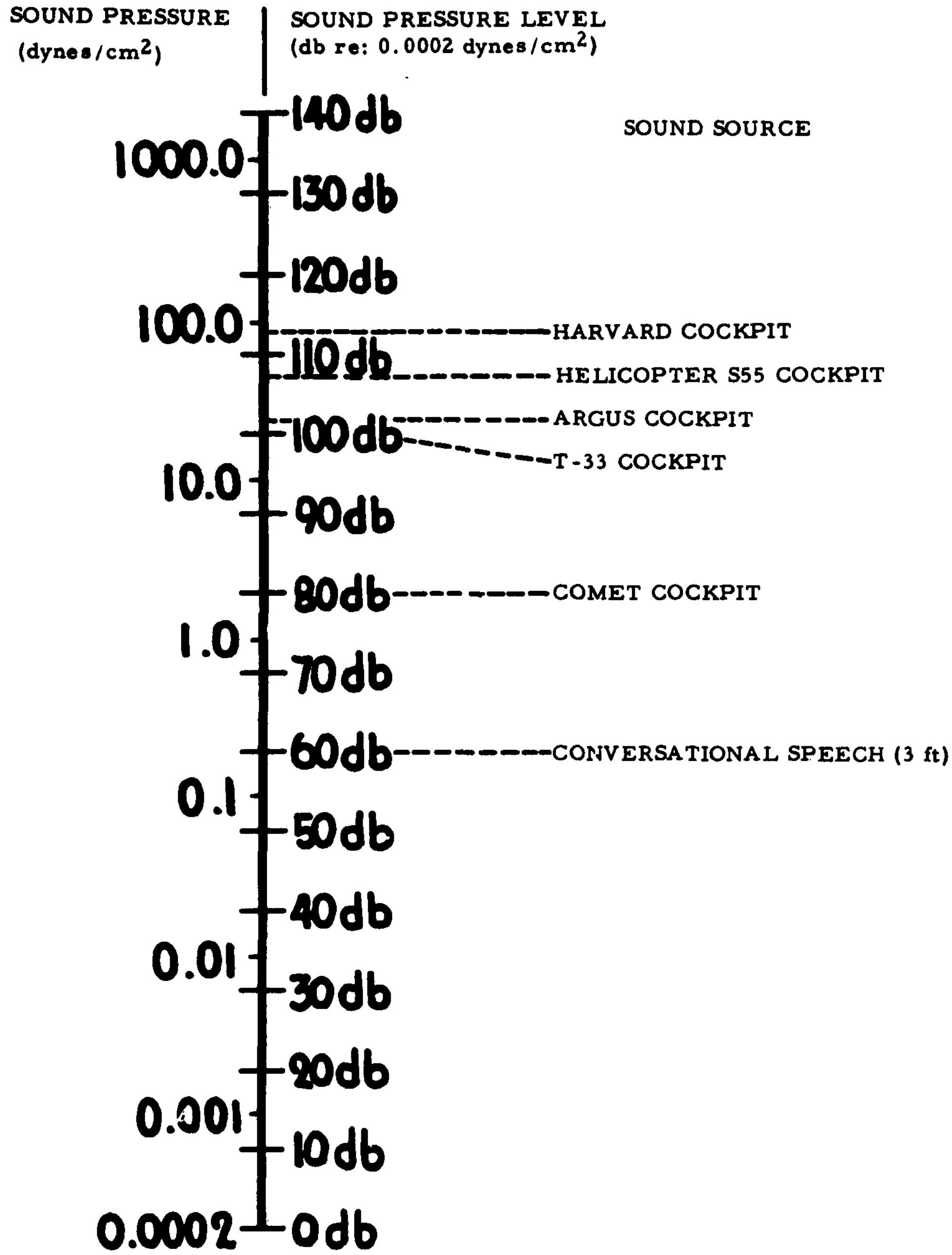
(a) speaking clearly;

(b) the use of standard phraseology; and

(c) audio equipment with adequate speech transmission characteristics.

TABLE I

Sounds and Sound Pressure Levels



Voice communications in high noise level areas without the aid of radio can be dangerous due to misinterpretation or simply not hearing the message. Hand signals should be used where possible. When walking in areas of high noise level and moving aircraft, great care should be taken since you would probably not hear a shouted warning.

(7) Increased effort is required to maintain performance and efficiency when exposed to continuous noise levels of 110 to 115 db for even short periods. Extended exposure may cause a noticeable drop in your efficiency if you do not work at maintaining it.

C. Protection from Noise

(1) You can minimize the effects of noise by:

(a) knowing about noise;

(b) avoiding areas of high noise level;

(c) having periodic checks of your hearing ability; and

(d) using noise protection devices.

(2) The wearing of ear plugs or ear cups in areas where the overall noise level is below 100 db will not only provide protection to the hearing mechanism but will also increase your listening intelligibility by 5 to 8 per cent.

(3) Protect yourself from noise by:

(a) wearing a well fitting helmet which will not only protect you from hearing loss but will also improve speech reception;

(b) if aircrew, wearing liquid seal ear cups rather than ear plugs; and

(c) when you suspect a hearing loss, consulting your Flight Surgeon or Medical Officer without delay.

TABLE II

Hearing Protection Criteria for Long-time Hazardous Exposures to Piston and Jet Engine Noise

Overall noise level (db re: 0.0002 dyne/cm^2)	Exposure time	Type of protection
85-100	Over 4 hours a day	Optimum ear plugs *or* earmuffs
100-130	Any	Optimum ear plugs *or* earmuffs
130-150	Any	Optimum ear plugs *and* earmuffs
150-	No exposure permitted	

CHAPTER 15

VISION

A. Introduction

(1) When you fly, your only direct contact with the world is through your eyes. Even though your eyes may be perfect you must use them properly and know their limitations in order to gain the most from your vision. This chapter will help you to know your eyes and what you can do with them.

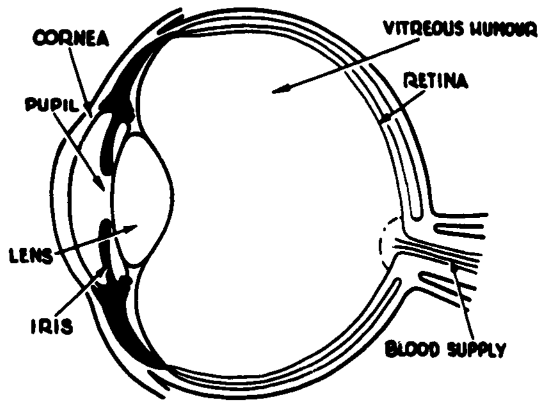


Fig. 21 The eye in horizontal cross-section

(2) The only means of orientation that you can trust in flight are your eyes and instruments. If you have visual contact with the world, you can trust it. However, if you lose this contact, don't trust the 'seat of your pants' or your sense of balance - these senses can lead you astray. DEPEND ON YOUR INSTRUMENTS. When visual contact is unreliable, as in haze, over glassy water, or against glare, do not hesitate to go on instruments.

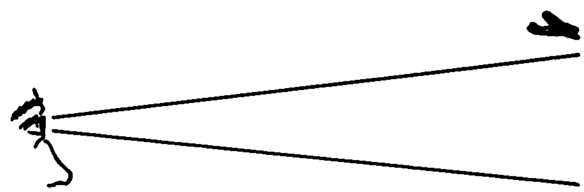
B. Visibility - Introduction

(1) Your vision in daylight is carried on by the 'day nerves' or 'cones'; these function in levels of illumination between full sunlight and moonlight. As these cones or day nerves are concentrated at the centre of the retina, vision is sharpest straight ahead along the direction in which you are looking. Only large objects can be seen to either side.

(2) With increasing distance, objects become smaller, may be covered with haze, and have little contrast with the background. Therefore, though your eyes may be perfect, your visual range is limited - don't try to find a one-man raft if searching from 10,000 feet *(3,048 metres)*.

C. Scanning

For small objects the limits of your vision may be illustrated as a long cone extending in the direction you are looking. (Figure 22). To search, you must move your head and eyes so as to carry the cone back and forth across the sky. Develop a scanning technique to sweep everywhere and miss nothing. A regular pattern of scanning is tiring but is the only efficient method of search.



THE LONG CONE REPRESENTS THE AREA OF MOST ACUTE VISION. THE MAN WILL NOT SEE THE SMALL AIRCRAFT UNLESS HE TURNS HIS GAZE DIRECTLY TOWARDS IT....
(DAY VISION)

Fig.22 Field of vision

D. Depth Perception

(1) You are aware of distance. In aviation, several important clues help you judge how far away an object is. For instance, the farther away an object is the smaller it becomes and it lies in front of more distant objects. As your aircraft moves, near objects pass by at great speeds; distant ones more slowly. During landing or take-off you continually use your depth perception and all these clues.

(2) Under certain conditions depth perception can be lost entirely; when flying in bright light over snow, 'white-out' can occur due to the glare from reflected light. Another situation in which depth perception is impaired considerably occurs when coming in to land on glassy water or a water-covered runway.

E. Aids to Vision

Certain aids to vision, such as corrective spectacles, anti-glare spectacles, and visors, are provided. Look after these and see that they are kept clean and in good condition. Visors and anti-glare spectacles should, of course, only be used when you are actually confronted by conditions of glare.

F. Hindrances to Vision

Due to the design of some aircraft the pilot's field of vision is limited from the outset. Other hindrances, such as a dirty windscreen, are not only a distraction but definitely dangerous; therefore a clean canopy should be included in your external check. Glare need not be a hindrance to vision if proper use is made of your protective equipment. Other factors detrimental to vision, such as smoking, alcohol, and high 'G', are discussed elsewhere.

G. High Altitude

(1) Unusual visual difficulties may occur when flying at high altitudes. The sky is dark and the sun very bright. When flying into the sun there is intense glare, yet the cockpit is in deep shadow. The reverse occurs when flying down sun as the cockpit is now brightly illuminated and the sky is black. Visual search under these circumstances is extremely difficult.

(2) At high altitude there are no visual reference points and aircraft spotting and interception are unreliable. This problem is made even more complex by the high speed of modern aircraft.

H. Night Vision - General

(1) The night nerves or rods are responsible for vision at very dim levels of illumination and are condensed in the area 5 degrees to 20 degrees from the centre point of the retina.

(2) Contained within these rods is a photo-chemical substance known as visual purple which is sensitive to dim light. When exposed to bright light it is 'bleached', thus losing its function, and consequently one is temporarily blinded if this occurs at night. After exposure to a bright light the rods take a considerable time to regain their maximum sensitivity; this is called 'dark adaptation time'.

I. Dark Adaptation

(1) Dark adaptation is the accumulation or regeneration of visual purple in the rods during periods when little or no light enters the eye. The rods require at least 30 minutes in total darkness to attain maximum sensitivity after exposure to a bright light.

(2) The rods are almost completely insensitive to red light, therefore red goggles worn for 30 minutes before night vision is required will give satisfactory dark adaptation. Should it be necessary to use a bright light in the cockpit at night, one eye should be covered during the period of exposure so that when the source of light is removed the covered eye will still be completely dark adapted.

J. Contrast Discrimination

(1) Objects are seen at night only by being either lighter or darker than their background. These contrasts can be seriously interfered with by light reflected from windscreen, by fog or haze, and by scratched or dirty visors or canopies. Therefore, it is essential that windscreen and visors be kept clean for night operations.

(2) Contrast differences can also be used to good effect at night to track an unidentified aircraft. When flying over dark areas, such as land, you should fly below the target; when flying over white clouds, snow, or moonlit water, fly above the target.

(3) Under conditions of low illumination other aircraft can be more easily spotted from either above or below rather than from directly behind. The image on the retina is much larger from the former positions and so there is less likelihood of losing contact in the darkness.

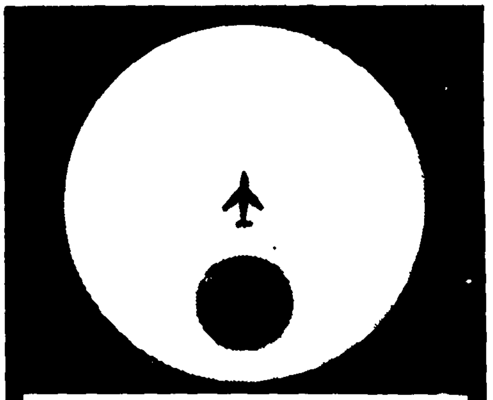
K. Effects of Diet, Hypoxia, and Carbon Monoxide on Night Vision

(1) Vitamin A is an essential factor in the formation of visual purple and a normal diet contains ample quantities of this substance. Other vitamins, B and probably C, are also important and these too are plentifully supplied in service rations.

(2) Hypoxia, whether due to an insufficient oxygen supply or carbon monoxide poisoning, has a detrimental effect on night vision, the visual purple in the rods being extremely sensitive to oxygen lack. Even after smoking three cigarettes, (which gives a carbon monoxide saturation of 2 to 4 per cent), your visual sensitivity is decreased by approximately 15 per cent.

L. Scanning at Night

(1) As the day nerves or cones do not function at levels of illumination below that of bright moonlight, central vision is lost at night and small objects directly ahead will not be seen. To see a small object at night, therefore, the vision should be fixed on a 5 to 20 degree circle from it.



The aircraft can be seen in the same amount of light by looking below (as is shown here), above, or to one side of it so that it is not obscured by the central blind area.

Fig.23 Off-centre vision

(2) Several methods may be used for carrying out a visual search at night, but for general purposes two simple methods are described:

(a) In one system, the visual sweep is made horizontally (Figure 24). Eye movements should be slow and at the end of the transverse movement, the gaze should be dropped and the movement repeated, this time in the opposite direction. On a dark night the sweep should be reduced, while on a clear moonlight night the scan can be increased in all directions.

(b) In the other procedure, the area is divided into four imaginary squares projected into space in any direction. Commencing at the top left, the scan is passed to the bottom right, from here to top right, and then down and across to the bottom left. A pause of two or three seconds should be allotted to each square, and a rather shorter pause half way along each diagonal. As it is possible to see an object and yet not appreciate its presence, it is essential to bear in mind what is being searched for.

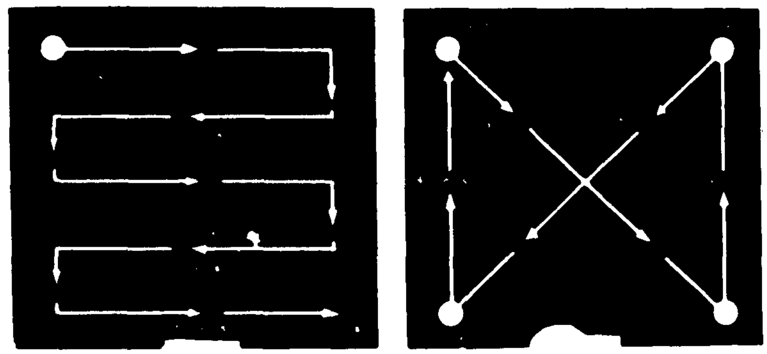


Fig. 24 Scanning at night

M. Autokinetic Movement

If you stare at a fixed light in an otherwise dark room you will soon experience the illusion that the light has begun to move about erratically. This illusion is known as the autokinetic phenomenon. Occasionally this phenomenon may occur while you are flying at night if you continually stare at a tail-light ahead of you and it will often cause a star to move in such a way as to be mistaken for another aircraft. This effect can be overcome by moving the eyes about rather than staring at any one point.

N. Hints for Improving Night Vision

The following aids may improve night vision:

(a) know how to scan properly and work out an efficient sky search plan for your particular aircraft and position - short, regularly spaced eye movements will enable you to see more than will wide sweeping movements and this applies as much at night as during the day;

(b) keep windscreens clean;

(c) to preserve adaptation, do not expose the eyes to bright light;

(d) turn out non-essential lights within the aircraft and keep essential lights as dim as possible;

(e) use low-intensity red light whenever possible at night;

(f) improve night vision by practising 'off-centre viewing' of dark objects on dark nights;

(g) use oxygen from the ground up on all night flights; and

(h) do not stare at isolated points of light at night.

O. Care of Equipment

All spectacles and visors should be kept scrupulously clean and free of scratches. Washing with soap and water and drying with a soft cloth are recommended. Plastic visors scratch very easily and every precaution should be taken to protect them from damage. When not in use, all eye protective equipment should be stored in suitable containers.

CHAPTER 16

SUMMATION OF PHYSIOLOGICAL STRESSES

A. General

At one time or another practically everyone has had spells of dizziness, if not actual unconsciousness. These may occur as a result of being 'boarded' during hockey, standing on a parade square during a hot summer's day, or even as a result of indiscretion 'the night before'. Normally these spells pass off without mishap and are forgotten. If such dizziness occurs in the air, however, particularly if one is in charge of an aircraft, it warrants more attention. Recent aviation medical investigation has demonstrated that these events, sometimes resulting in 'near misses', are definitely occurring during flight. The incidence of such attacks, especially those of a mild degree, is probably common enough to merit serious consideration. The combination of circumstances which causes such spells in normal people is medically well understood. For this reason - and since the consequences can be considerable - preventive measures are available to those who wish to keep informed on the subject.

B. The Mess Trick

(1) Perhaps the simplest combination of circumstances which will induce physiological confusion and unconsciousness is illustrated in the well known 'Mess Trick' which will cause fainting in most *normal* people. It can be performed in several ways, all of which will evoke the same combination of responses in our body. To illustrate, if a normal individual breathes very deeply for about 20 times while squatted down, and then rapidly stands up and closes his windpipe and blows out in order to increase the pressure within his chest, he will probably pass out cold. The act can be *dangerous* since during the unconscious period muscular control is lost and one may fall heavily. If the head is struck, serious injury can result.

(2) As consciousness filters back, there is usually a short period of convulsive movement followed by a clearing of consciousness which requires some seconds before full orientation in space and time is attained. Besides feeling very foolish at finding himself sprawled on the floor in an undignified manner, it takes a man a while to remember where he is and what his mess friends are laughing at! He will be content to go quietly away and sit down; he may be pale, sweaty in the palms, and somewhat physiologically as well as psychologically shaken. School-boys have been known to use this manoeuvre to 'take down' any member of their group deemed to require such treatment.

(3) When an experience of this sort occurs in flight it can be so embarrassing that the pilot will be loath to discuss the matter afterwards. However, since the factors involved are under our control and the consequences may be serious, it is well to have some knowledge about them in order that pilots may avoid an unwitting performance of the 'Mess Trick' in the air.

(4) Medical study of the example just cited has shown that fainting and disorientation result from a combination of various factors:

(a) 'G' effects, i.e., those resulting from the postural change of standing up from the squatting position;

(b) hyperventilation from overbreathing; and

(c) circulation effects caused by increased pressure within the chest and decreased pressure within the belly.

(5) Physiologists now know that these factors combine to produce a single overall effect; they reduce the blood flow to the brain. Any one factor will not by itself cause sufficient interference to elicit symptoms; the act of suddenly standing erect in the Mess Trick, for example, will merely produce the equivalent of a 2 to 3 'G' change. The important fact to remember is that these individual effects, when combined, may cause a significant reduction in the brain's blood supply.

C. Oxygen and Blood Sugar

(1) We have seen that the essential factor inducing periods of dizziness or unconsciousness arises from the combination of a variety of circumstances whose sum effect is to reduce the minute-to-minute energy supply to the brain. Of course we all know that high 'G' lasting for an appreciable period of time can produce unconsciousness, as can profound oxygen lack. In the present instance we are dealing with the summation effect of smaller changes.

(2) In order for consciousness to be maintained, a constant supply of energy to the brain is needed and it is normally supplied by an adequate flow of blood which delivers the required energy-producing materials. These include both oxygen and fuel, e.g., blood sugar. Normal brain functioning demands a constant supply of blood containing a normal amount of oxygen and fuel. The importance of these elements is shown by the fact that approximately one-third of the total blood pumped by the heart is delivered to the brain. A reduced supply of energy will result from:

(a) a diminished volume-supply of blood in the brain; and

(b) a diminished content of energy-producing materials in this blood.

(3) Dealing with the latter factor first, we have seen that the energy-producing materials in the blood consist of oxygen and fuel. (The problem of oxygen supply is discussed in Chapters 1, 2, 3, 4, 5 and 6.) It will suffice to remind ourselves that a continuous supply of oxygen is required by the body, that the brain fails first if the supply is reduced, and that the brain at best possesses only a few seconds' reserve supply of oxygen. The system is critical. Similarly the brain has only a small reserve of blood-sugar fuel and is thus highly dependent on a continuous supply of it.

(4) The amount of sugar in our blood is normally controlled within limits despite the fact that we usually take in a new food supply only three times a day. However, this control in turn has its limits; about 11 o'clock in the morning and 4 o'clock in the afternoon our blood sugar is apt to be on the low side, particularly if we have not had a proper food intake or if we have been under stresses arising out of the flight conditions imposed during the day. Low blood sugar is sensed by that 11 o'clock 'gone' feeling which is often accompanied by tremor or increased gurgling within the

belly. These internal reactions are closely allied to the normal sensation of hunger and can be alleviated within five minutes by taking sugar. (Remember that soft drinks contain 10 per cent sugar.) However, this sugar must not be a substitute for the next meal. Unless more food is taken subsequently, the attacks may recur in more aggravated form. Remember that, though one's eating is often a matter of habit, good eating habits are a matter of intelligence. Taking off without breakfast is like flying without checking the fuel - and results can be the same.

(5) At the same time increasing one's overall food intake in the 24-hour period can eventually lead to dangerous overweight. There is a proper way to use both your appetite and your throttle.

D. Effect of 'G'

(1) Now, what are the factors in flight which can diminish energy delivery by diminishing blood flow? How may we accidentally perform the 'Mess Trick' on ourselves in the air?

(2) Among the mechanisms capable of reducing blood flow, perhaps the effect of 'G' is the easiest to understand. We are all aware that blood flow to the brain is reduced by positive 'G'. The subject is dealt with at length in Chapter 7. For our own purposes it will be enough at the moment to recall that:

(a) increased positive 'G' always produces some reduction in the blood flow to the brain;

(b) at levels below black-out this may not be noticed (unless combined with other factors);

(c) repeated 'G' may sometimes tend to exhaust even the slight reserves in the brain;

(d) attitude (posture) in the aircraft can play a part; and

(e) all these effects can be minimized by wearing a 'G' suit.

E. Hyperventilation

(1) Probably the second most common cause of diminished blood supply to the brain occurring in flight is hyperventilation. It acts in two ways, shutting down the brain blood vessels (making the brain become 'pale'), and diverting the blood to other parts of the body as a result of the converse dilation of the blood vessels of those parts. Hyperventilation is an ingredient of all forms of the 'Mess Trick'. (See Chapter 5.) In addition to the blood flow changes wrought by hyperventilation it is probable that the blood has difficulty giving up its oxygen to the brain because of the chemical changes which result from the 'blowing off' of excessive amounts of carbon dioxide.

(2) Hyperventilation occurs when we overbreathe beyond our physical requirements. Overbreathing following heavy work is not hyperventilation; but overbreathing due to anxiety, or as a result of a leaking inspiratory valve, or from a wrongly diagnosed

air hunger, will produce the effect we have discussed. The symptoms of hyperventilation may be indistinguishable from those of hypoxia from oxygen failure and should be assumed to be the latter until proved otherwise. (See Chapters 5 and 6.)

F. Prevention the Best Cure

The best treatment for hyperventilation is prevention. This may be accomplished by knowing the facts and avoiding the various conditions which cause hyperventilation.

G. Disorientation and Vertigo

A third cause of diminished brain blood supply which can occur in the air is disorientation and associated vertigo. One of the commonest acute reasons for it is turning the head rapidly in a plane at right angles to that of a close turn in flight. The disorientation falsely sensed is that of rotation in the third plane and is associated with varying degrees of vertigo like that experienced in rough weather. These effects can be exaggerated if they occur when the brain blood supply has already been reduced by any of the other causes. You may actually feel that the aircraft is out of control. This vertigo, however, results in a further diminution of blood to the brain because of diversion of blood into the abdomen - again that 'gone' feeling. Once more, prevention is the answer to the problem. If you have to rotate your head during a turn or in rough weather, do it slowly. If you can move your eyes without turning your head, so much the better.

H. Excessive Heat

A fourth cause of the diversion of blood away from the head is excessive heat which may sometimes be generated in flight. Fainting on the parade ground on a hot summer's day results from a diminished supply of blood to the heart following dilation of the blood vessels in the extremities. In an aircraft, diminished blood volume from excessive sweating without the balance-restoring properties of an adequate fluid and salt intake may cause similar fainting. It pays to keep as physiologically 'cool' as you can.

I. Flickering Light

(1) A fifth possible cause of diminished blood to the brain stems from the peculiar effects that occasionally result from looking at a flickering light. This effect depends on the intensity and frequency of the light flicker and may even lead to fainting in sensitive individuals.

(2) The prevention of this effect is simple. If for any reason you experience a flickering light condition - under a helicopter's rotor or flying in and out of clouds on a bright day - keep your eyes averted and concentrate on something less bright. 'Black-outs' have been reported during landings into the sun because the pilots were looking through an idling propeller - a rare point, but worth knowing.

J. Additional Factors

(1) Besides the conditions we have discussed here as capable of reducing the brain's energy supply, there are further medical factors which tend to aggravate the problem.

Most important and probably most common of these is influenza. Everyone knows the 'gone' feeling that accompanies 'flu'. Combined with some of the physiological states mentioned earlier in this article, it will assume the role of the last straw that broke the camel's back. Excessive coughing may aggravate the condition, increasing pressure within the chest; and acute changes in fluid supply can also play havoc in the form of a hangover (as shown by the absence of normal wrinkles in your forehead in the morning). Diarrhoea can prove debilitative in a similar way - as will any complaint which causes a man to sweat unduly - and prolonged fatigue itself may culminate in virtual 'blackout'.

(2) What happens during the 'Mess Trick' we referred to earlier is that the brain becomes abnormally 'pale'. We cannot see the blood supply to our grey matter but, like the normal, rosy hue of our faces, it can be influenced by many factors. By recognizing them as they appear and by preventing their combination we can ensure that those factors will never exceed our normal adaptability. Remember that normal individuals vary considerably in their response to them. The wise man comes to know his own capacities as a result of his experience and adapts himself accordingly. Keep in mind also that your 'G' tolerance and visual acuity having nothing to do with intestinal fortitude or intelligence.

K. Confidence Through Knowledge

(1) There is a vital practical consideration that arises out of 'near misses' caused by partial or complete loss of consciousness. Obviously a 'near miss' could place your aircraft in an impossible position at a time when you are otherwise confused. Skilful handling of such an emergency will depend entirely on a pilot's familiarization with the right drill. Every action must be split-second fast and automatic. There's not time to check the book. Review it now and avoid the squeeze.

(2) Right here would be a good place to remind readers about reporting a physiological 'near miss' episode in the air. Whether the cause involves yourself or your equipment, the men to see are the Medical Officer and the Flight Safety Officer. Don't risk a life by silence.

(3) One of the great problems facing Aviation Medicine lies with the inability of the Medical Officer to be on hand in the air when he is most needed and would have most to offer. Medical information has to be passed out and self-applied. Providing such aviation first-aid is part of the job of the medical branch in a modern air force. The human body functions in a wonderful manner, but it does require knowledge and care if optimum efficiency is to be obtained from it, particularly in view of the virile challenge of modern manned flight.

(4) The danger in providing our aircrew readers with this medical information is that it may constitute the 'little learning' which can become a 'dangerous thing'. To illustrate this point, did you know that, during their training, medical students often imagine they are developing all the diseases they study? It's not a good habit. Keep your knowledge of the 'Mess Trick' from becoming a cause of hyperventilation or neurotic concern about yourself.

(5) We sincerely believe that the modern pilot learns physiological poise as a result of true physiological knowledge. 'Know thyself' is advice of the highest order for the human factor in modern manned aircraft; but don't let 'yourself' become all you know. There's more than oxygen and sugar in your head, although a continuous supply of these is essential if you are to remain 'on top'.

INDEX

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